UNIVERSITY OF IOWA STUDIES IN ENGINEERING

BULLETIN 6

AN INVESTIGATION OF SOME HAND MOTIONS USED IN FACTORY WORK

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PUBLISHED BY THE UNIVERSITY
IOWA CITY, IOWA
February, 1936

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I. INTRODUCTION

1. Object and Scope—Since the cost of labor is a major consideration in the operation of the factory and the office, much thought has been given to the improvement of labor effectiveness. However, most work along this line has been of practical nature with the immediate objective of finding a better way of doing a given task and then setting a standard time or piece rate for this task.

Few investigations have been made in this country in an attempt to discover fundamental data that are common to all kinds or classes of manual work. The studies reported in this bulletin were made with this objective.

The first part of the bulletin presents several preliminary investigations of hand and finger motions using the micromotion study technique. That is, motion pictures were made of factory operators at work. A special clock was used to indicate time on the motion picture film which made possible accurate measurement of the time required to make elemental hand motions such as move hand empty, grasp piece of material, carry material to fixture, insert it, etc.

As a result of these first investigations a more refined method of measuring and recording movements was developed. This new technique made it possible not only to study elemental motions such as moving an object by hand but also to investigate the component parts or increments of such a motion. The results of studies using this new method are presented in the second part of this bulletin.

Although the data were taken with the most meticulous care, and with all the accuracy attainable with the measuring devices that were used, the point must be noted that certain inevitable variations were introduced as a result of the fact that the movements being measured were those of human, as distinct from purely mechanical, subjects.

As general conclusions could safely be based only on investigations of a much broader scope than those reported in this bulletin no such general statements are presented.

These studies may, therefore, be considered as preliminary in nature and the conclusions at the end of each of the several investigations are based merely on the results of that particular investigation.

2. Acknowledgments—The investigations described in Part I were made at the plant of the L. C. Smith and Corona Typewriters Inc. in Groton, N. Y., through the kind permission of the production manager, J. E. Keller.

The writer wishes to express his great indebtedness to Dexter S. Kimball, Dean of the College of Engineering; and to Herman Diederichs, Head of the Department of Mechanical Engineering, of Cornell University, for the use of equipment and apparatus. He would also acknowledge his indebtedness to Professor M. A. Lee who read the manuscript and made many helpful suggestions regarding it.

The investigations described in Part II were made in the Time and Motion Study Laboratory[1] at the University of Iowa. The writer is particularly obligated to Professor Huber O. Croft, Head of the Department of Mechanical Engineering, for assistance which made these investigations possible. Likewise, special thanks are due two graduate students in Mechanical Engineering, A. B. Cummins who built the apparatus and Wayne J. Deegan who conducted the tests described in Part II.

[1] For a description of the laboratory see: "The New Emphasis in Time and Motion Study" by Ralph M. Barnes, *Journal of Engineering Education*, Vol. 16, No. 3, p. 239-248, Nov. 1935.

PART I

A STUDY OF HAND MOTIONS USING THE MICROMOTION STUDY TECHNIQUE

The following studies were made for the purpose of determining the nature of some common hand and finger motions typical of those used in ordinary factory work. The micromotion study technique was used for analyzing and measuring the motions.

II. EQUIPMENT USED IN MAKING THE STUDIES

A description of the equipment commonly used in making micromotion studies is readily available,[1] and will not be described here. However, specifications of the equipment used in conducting these particular experimental studies will be given in detail.

3. Motion Picture Camera—An Eastman Model A motion

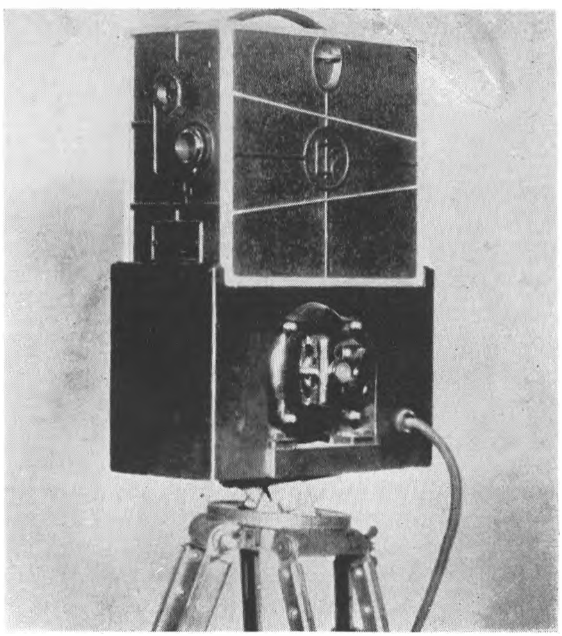

FIG. 1. Constant speed motor driven motion picture camera.

[1] See "Motion Study" by Ralph M. Barnes, published by Edwards Brothers, Inc., Ann Arbor, Michigan.

picture camera of the hand cranked type was converted into an electric motor driven model by connecting a constant speed electric motor to the camera drive shaft through a train of brass and fiber gears as shown in Fig. 1. By changing gears, speeds of either 1000 or 2000 frames per minute could be obtained. When speeds higher than 2000 frames per minute were needed the motor was disconnected and the "slow-motion" hand crank used.

An enlarged print from a strip of film made at a speed of 1000 frames per minute is shown in Fig. 6. The time interval that elapsed from one frame to the next on this film was exactly 1/1000 of a minute. The motions of the hand shown as taking place during the exposure of the 54 frames reproduced in Fig. 6 required 54/1000 (.054) of a minute.

4. Camera Speeds—The amateur motion picture camera operates in such a way that one frame, or the film for one exposure, is suddenly "pulled down" or jerked in front of the lens of the camera during an instant when the camera shutter has closed the lens. After the film is in place, the rotating shutter opens and permits the subject to be photographed. The shutter then closes and the next frame is pulled down for the next exposure, and so on. The shutter is closed from one third to one half of the time (depending on the design of the shutter) while the camera is in action. The ratio of the size of the open segment in the shutter to the closed segment determines the exposure time for one rotation of the shutter. The shutter makes one complete revolution each time an exposure is made. Therefore, if the camera is operating at the normal speed of 16 exposures per second, and the camera has a shutter with an open segment of 180 degrees, then the time that the lens will be open during one revolution is 1/16 x 180/360 or 1/32 of a second.

The motion picture camera photographs intermittent scenes. In photographing moving subjects there is an instant (1/32 of a second in the above case) between successive exposures during which no record of action that has been taking place is made on the film. It is for this reason that successive frames on the film show the moving object at different points along its line of motion (see enlarged print in Fig. 6). The hand reaching for an object is shown first a foot away from the object, then ten inches, then eight inches, etc. In cases where the movement of the subject is relatively rapid, the moving object appears to be blurred. The right hand in Fig. 6 appears blurred in exposure 2, 7 and 8. This blur is due to the fact that during the short instant when the shutter was open the hand moved a sufficient distance to cause the blur. These blurs are eliminated by exposing the film at a more rapid rate. Had the picture been made at 32 instead of 16 exposures per second, the time during which the shutter remained open would have been but 1/64th of a second, and the hand would have moved but one half the distance. This would have reduced or entirely eliminated the blur.

With the camera operating at normal speed, it frequently happens that the hand, for example, changes direction entirely, while the shutter is closed. In the case of an operator reaching for an object, the hand might be shown moving to the right on one frame of the film. On the next frame it might be shown moving to the left. During the instant that the shutter was closed, the hand had actually continued to move to the right, grasped a piece of material and was on its return movement when the next exposure was made. For very accurate studies, such hidden motions are undesirable. To prevent this it is necessary to operate the camera at higher speeds.

For ordinary micromotion study work the normal camera speed was found to be satisfactory. For studying rapid hand motions it was necessary to use twice normal speed, and in evaluating very short and fast motions such as a "sliding grasp," speeds of from 4000 to 5000 exposures per minute were required.

5. Microchronometer—Since the number of exposures made on the film in any given time interval will depend upon the speed of the camera, and since the speed of our hand cranked camera was neither known nor constant, it was necessary to place some very accurate timing device in the picture so that the time interval from the exposure of one frame to the exposure of the next would be indicated on the film.

A clock, with fast moving hands, called a microchronometer was used for this purpose. The clock shown in Fig. 4 was driven by a small synchronous motor. It had 100 equal divisions on the dial, the large hand made twenty revolutions per minute and the small hand two revolutions per minute. Each division on the dial indicated 1/2000 of a minute. By changing the gear ratio inside of the clock, the large hand made fifty revolutions per minute and the small hand five. Using this latter arrangement it was possible to read time intervals of 1/5000 of a minute without interpolation. The clock was operated at this fast speed only when the film was exposed at 2000 frames per minute or faster. When the electric motor was used to drive the camera the microchronometer was not needed.

6. Projector—A small light weight projector with a low power bulb was used for analyzing the film. A special hand crank was attached to the projector so that one turn of the crank advanced the film one frame in front of the lens. By giving this crank a quick turn the frame of film was pulled down in front of the projection lens so quickly that the movement of the subject could be noted on the screen. This aided in finding the points where motions began, ended, or changed direction.

A counter for indicating the number of frames was mounted on the projector and proved to be valuable in analyzing film made with the motor driven camera.

III. DEFINITION OF THERBLIGS

F. B. Gilbreth, in his early work in motion study, developed certain subdivisions[1] or events which he thought common to all kinds of work. He coined the word "therblig" in order to have a short word with which to refer to any of these eighteen elementary subdivisions of a cycle of motions.[2]

The therbligs mentioned above together with their mnemonic symbols and color designations are shown in Fig. 2. The definitions of these therbligs are given below and were used in the studies reported in this bulletin.

1. Search (Sh.)

Search refers to that part of the cycle during which the eyes or the hands are groping or feeling for the object. *Search* may be performed with either the eyes or the hands.

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[1] Certain European investigators have used other subdivisions of work. See: Thun, R., "Work Studies with the Help of the Cinematograph," *International Review of Educational Cinematography*, Vol. 2, No. 7-8, p. 849-885, July-August, 1930.

For a slightly modified statement of Gilbreth's therbligs see: *Cost and Production Handbook*, Ed. by L. P. Alford, p. 580.

[2] Gilbreth, F. B. and L. M., "Classifying the Elements of Work," *Management and Administration*, Vol. 8, No. 2, p. 151, August, 1924.

Name of Symbol	Therblig Symbol		Explanation--suggested by	Color	Color Symbol	Dixon Pencil Number
Search	Sh.		Eye turned as if searching	Black		331
Find	F.		Eye straight as if fixed on object	Gray, heavy		399
Select	St.		Reaching for object	Gray, light		393
Grasp	G.		Hand open for grasping object	Lake red		369
Transport loaded	T.L.		A hand with something in it	Green		375
Position	P.		Object being placed by hand	Blue, heavy		376
Assemble	A.		Several things put together	Violet, heavy		377
Use	U.		Word "Use"	Purple		396
Dis-assemble	D.A.		One part of an assembly removed	Violet. light		377
Inspect	I.		Magnifying lens	Burnt ochre		398
Pre-position for next cycle	P.P.		A nine-pin which is set up in a bowling alley	Sky-blue		394
Release load	R.L.		Dropping content out of hand	Carmine red		370
Transport empty	T.E.		Empty hand	Olive green		391
Rest for overcoming fatigue	R.		Man seated as if resting	Orange		372
Unavoidable delay	U.D.		Man bumping his nose unintentionally	Yellow ochre		373
Avoidable delay	A.D.		Man lying down on job voluntarily	Lemon yellow		374
Plan	Pn.		Man with his fingers at his brow, thinking	Brown		378
Hold	H.		Carpenter's Vise	Lake red		369

FIG. 2. Symbols and colors for simultaneous motion cycle charts.

2. FIND (F.)

Find occurs at the end of the therblig *search* and represents more of a mental reaction than a physical movement. *Find* precedes the therblig *select*.

3. SELECT (St.)

Select refers to the choice of one object from among several.

In many cases it is difficult if not impossible to determine where the boundaries lie between these first three therbligs. For this reason it is usually the practice to combine them, referring to the group as the one therblig *select*. This practice was carried out in the studies reported here.

Using the broader definition, *select* then refers to the searching, finding and selecting an object. *Select* usually occurs between the therblig *transport empty* and the therblig *grasp*. However, there is no therblig *select* when parts are *prepositioned*, for in such cases *transport empty* is followed directly by *grasp*.

4. Grasp (G.)

Grasp refers to taking hold of an object, closing the fingers around it preparatory to picking it up. This therblig begins when the hand or fingers first make contact with the object and ends just as the object starts to be moved.

5. Transport Loaded (T. L.)

Transport loaded requires that a change in the location of an object be made. It is the moving of an object from one place to another. The object may be carried in the hands or fingers or it may be moved from one place to another by sliding, dragging, or pushing it along.

6. Position (P.)

Position consists of turning or locating an object in such a way that it will be properly oriented to fit into the location for which it is intended. It is possible to position an object during the therblig *transport loaded*. The carpenter, for example, may turn the nail into position for using while he is carrying it to the board into which it will be driven. *Position* usually follows the therblig *transport loaded* and precedes the therblig *use*.

7. Assemble (A.)

Assemble consists of placing one object into or onto another object with which it becomes an integral part. The therblig begins as the hand starts to move the part into its place in the assembly. The motion ends when the hand has completed the assembly and begins to release the part.

8. Use (U.)

Use may refer to an almost infinite number of particular cases but it always consists of manipulating a tool, device or piece of apparatus for the purpose for which it was intended. *Use* is the most important of all therbligs. It represents the therblig for which the preceding therbligs have been more or less preparatory and for which the ones that follow are supplementary. *Use* begins the instant the hand touches the device to be used and ends the instant the hand ceases the application and begins the next therblig.

9. Disassemble (D. A.)

Disassemble consists of separating one object from another object of which it is an integral part. The therblig begins when the hand starts to remove one part from the assembly. The motion ends when the hand has separated the part completely from the remainder of the assembly and begins the next motion.

10. Inspect (I.)

Inspect consists of testing a piece to determine whether or not it complies with standard size, shape, color, or other qualities previously determined. The inspection may employ sight, hearing, touch, odor, or taste.

11. Preposition (P. P.)

This therblig is the same as *position* with the added qualification that *preposition* refers to positioning an object in a predetermined place. Usually a holder, bracket or special container of some kind is used for holding the object in such a way that permits it to be grasped in the position in which it will be used. This eliminates the therblig *position* which would otherwise be necessary after the object was grasped. *Preposition* is the abbreviated term used for *preposition for the next operation.*

12. Release Load (R. L.)

Release load refers to that part of the cycle during which the hand is letting go of the object grasped—letting it slip out of the hand. This therblig begins when the object starts to leave the hand and ends as the object has completely separated from the hand or fingers. This therblig is a very short one and in most cases cannot be measured with the motion picture camera at ordinary speed. Some people arbitrarily assign a time value of 1/2000th of a minute[1] to this therblig.

13. Transport Empty (T. E.)

Transport Empty consists of moving the empty hand in reaching for an object. This therblig usually begins the instant that the previously held object is released, and ends when the therblig *select* begins, or else when the fingers come in contact with the object to be grasped if there is no *select* therblig.

14. Rest for Overcoming Fatigue (R.)

Rest for overcoming fatigue is a fatigue or delay factor or allowance provided to permit the worker to recover from the fatigue incurred by his work.

15. Unavoidable Delay (U. D.)

Unavoidable delay may result from either of the following causes:

(A) A failure or interruption in the process.

(B) A delay caused by an arrangement of the operation which prevents one part of the body from working while other members are busy.

16. Avoidable Delay (A. D.)

Avoidable delay refers to any delay of the operator for which he is responsible and over which he has control. It refers to delays which the operator may avoid if he wishes.

(A) The delay therbligs are assigned in most cases where there is a stopping of all motions of the hand.

(B) It is possible that there may be a delay caused by the worker making motions in an ineffective way.

[1] The time interval of 1/2000th of a minute was called a "wink" by Gilbreth.

17. PLAN (Pn.)

Plan refers to a mental reaction which precedes the physical movement, that is, deciding how to proceed with the work.

18. HOLD (H.)

The therblig *hold* has been used by some as a separate and distinct element. Strictly speaking it is a form of grasp and was considered as such by *Gilbreth*. *Hold* denotes the retention of the object after it has been grasped, no movement of the object taking place.

IV. OPERATIONS AND OPERATORS STUDIED

GROUP I

7. Link Forming Operation—In order to carry out a series of studies on hand motions it was necessary to select and obtain suitable types of factory work and the assistance of skilled operators. The facilities of the Groton Plant of L. C. Smith and Corona Typewriters Inc. were made available for these investigations.

A survey of the plant was made to find an operation that would lend itself to the studies to be made. The "Link Forming" operation was selected for the following reasons. The cycle was short, occupying less than one tenth of a minute, and was composed of 20 elements or therbligs. Several of the most important of these therbligs had very definite and clear cut starting and stopping points and were well adapted to the detailed study which was to be made of them. Part of the cycle repeated itself since the two ends of the link were formed in the same fixture in an identical manner.

The link was used in the portable typewriter and was made in

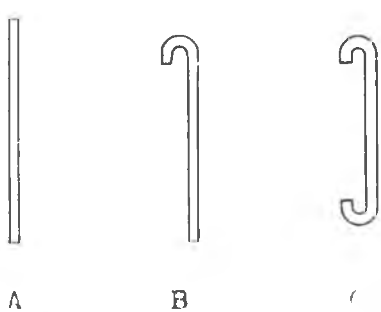


FIG. 3. Link for portable typewriter. A—soft steel wire; B—link with one end formed; C—finished link.

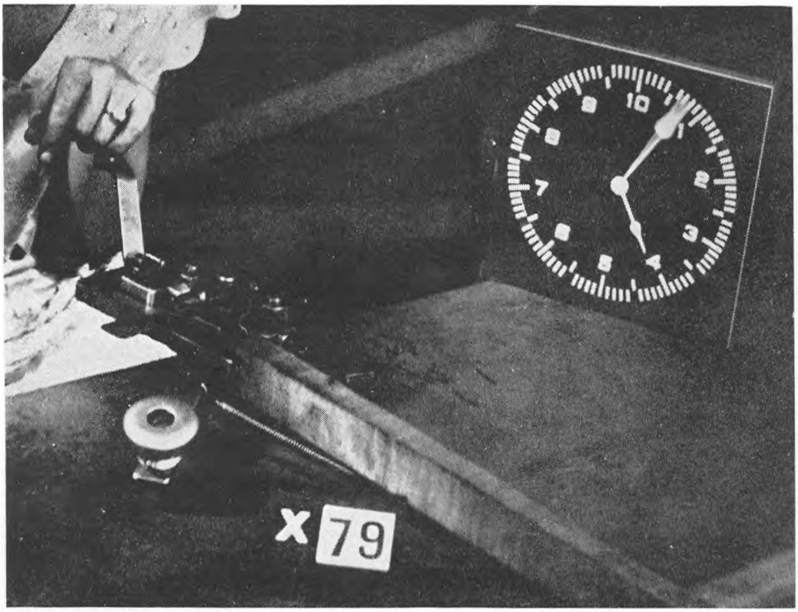


FIG. 4. Fixture for forming link for typewriter. The microchronometer is shown in the background.

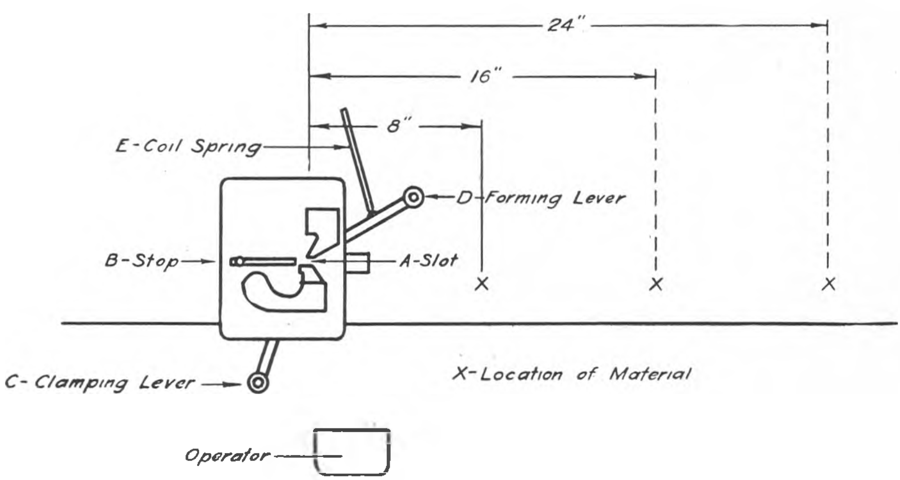


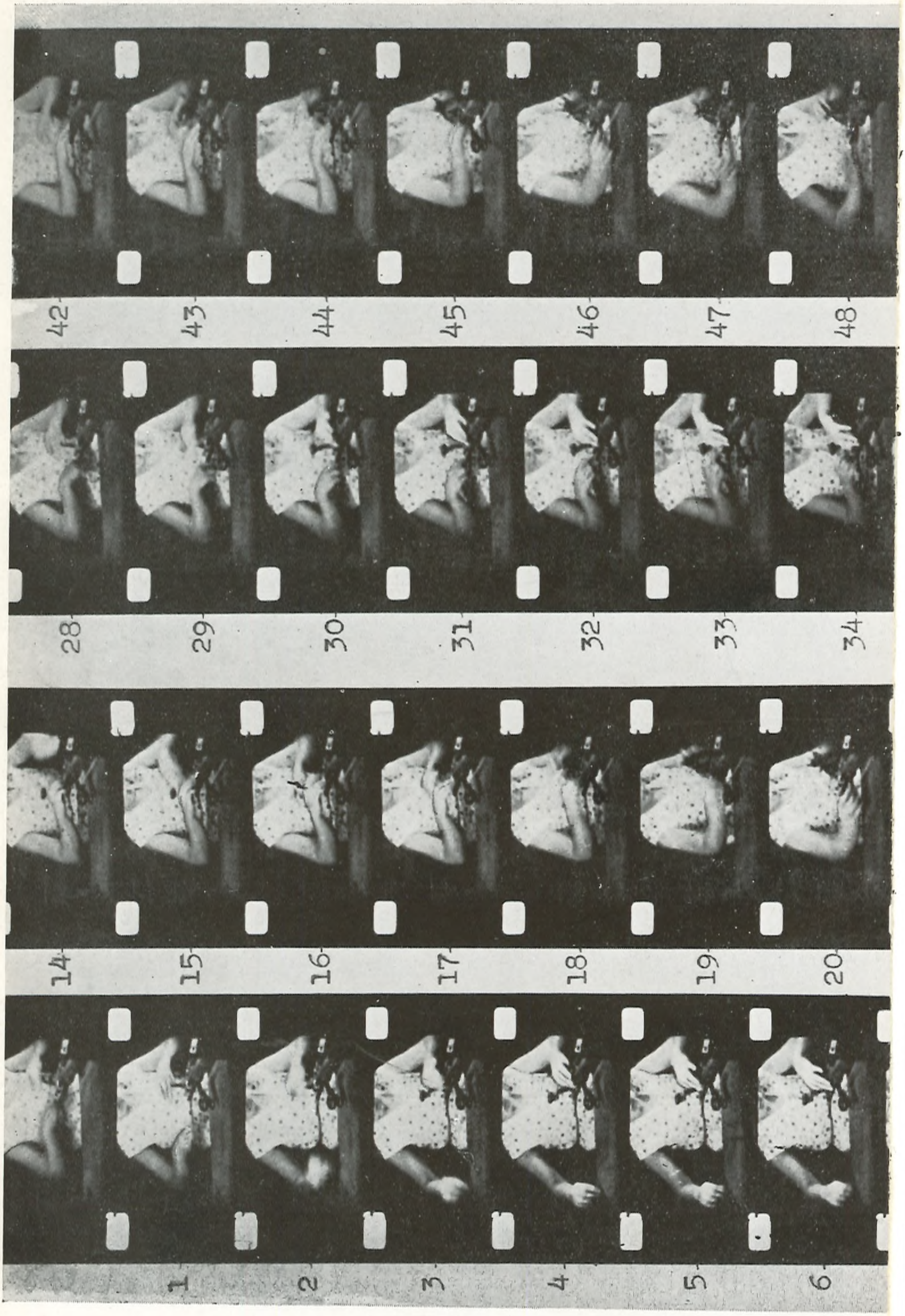
FIG. 5. Fixture and schematic layout of the work place for forming link.

various lengths depending upon its position in the typewriter. All studies were made on links of one size as shown in Fig. 3. Figs. 4 and 5 show the work place and the fixture used in forming the link.

The material from which the link was formed consisted of soft steel wire cut from wire stock, .045 inches in diameter to uniform lengths of 1¼ inches. The material was supplied to the operator in metal containers and the operator emptied the stock of cut wire onto the linoleum topped bench at the right of the fixture as she needed it. The link was formed in the following manner.

The pictures in Fig. 6 give a reproduction of each element of one complete cycle. The operator was seated behind the bench as shown in Fig. 5. The fixture was mounted securely on the bench so that its top surface was 2¾ inches above the top of the bench. The top of the bench was 27 inches above the floor. The material was spread out over the surface of the bench top so that it could be grasped more easily. The operator picked up one piece of material with the thumb and index finger of her right hand, carried it to the left and inserted it into the slot A in the fixture. See Fig. 5. The operator pressed the piece of material against a stop B in the fixture, and at the same time she clamped the piece into place by moving lever C to the left with her left hand. Then, with the right hand she grasped the knob of the forming lever D which extended to the right of the fixture and was about three inches above the top of the bench. The right hand rotated the forming lever in the clockwise direction about the center of the fixture as an axis, through approximately 180 degrees, the radius of rotation being 8 inches. The lever was moved in a plane parallel to the top of the bench. This movement of the lever formed the "hook" on one end of the link. The operator then returned the lever in the counter clockwise direction toward its original position. A coil spring E fastened to the forming lever and to the bench assisted the operator in returning the lever to its original position. This spring made it possible for the operator to release the forming lever after she had returned it through about one half of its return travel, the spring pulling the lever back the remainder of the distance.

After the operator had released the knob of the lever she moved her hand slightly to her right and into a position about four inches in front of her and waited an instant while her left hand removed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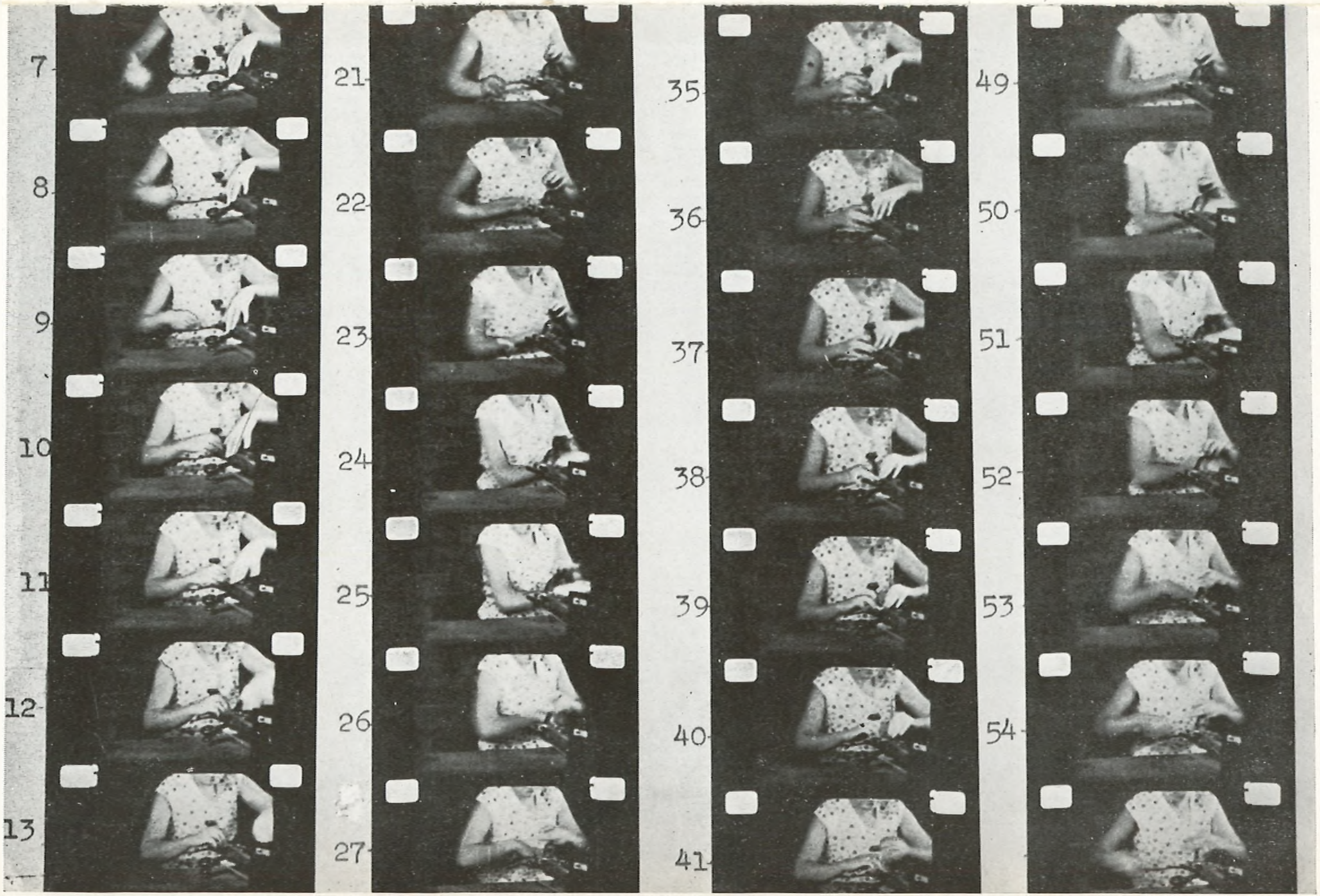

FIG. 6. Print of motion picture film showing one complete cycle of the link forming operation.

the half formed link from the slot in the fixture. Then the two hands together turned the link end for end and placed it back into the slot. Care was used to insure that the "hook" was turned in the proper direction so that after the link had been completely formed the two hooks would be on the same side. As the right hand held the link in place in the fixture the left hand moved the lever C to the left, clamping the link in the slot as in the first part of the cycle. The right hand then grasped the knob of the forming lever and as before, moved it through 180 degrees in the clockwise direction forming the second end of the link. While the right hand was forming the end of the link the left hand continued to hold lever C in its position as far to the left as it would go, clamping the link in the fixture while being formed. After the link was formed, the right hand returned the forming lever toward its original position, releasing the knob of this lever directly in front of the operator. She then moved her hand to her right to pick up a piece of material from the bench for the beginning of the next cycle. In the meantime the left hand released the knob of lever C and reached forward to remove the finished formed link from the slot in the fixture. The left hand then carried it to the left where it was dropped on top of the bench. During this time the operator was looking to her right where the right hand was grasping a piece of material from the top of the bench for the next cycle.

8. Operators Studied—Two operators were studied in the investigation. The one referred to as operator No. A1 was about forty years old and was an experienced and efficient operator. She was referred to by the foreman as an "all around worker." She had frequently worked on the link forming operation although that was not her regular job.

The operator referred to as operator No. A2 was about twenty years old and was an excellent worker. At the time the first link forming studies were made she had worked regularly on this operation. However, later in the year, due to lack of orders, this operator was used on many different kinds of work, and when the second series of studies of the link forming operation were made she had not worked on this particular operation for some months. The foreman considered operator A2 more highly skilled and a faster worker than operator A1.

The results of the studies made of operators A1 and A2 performing the link forming operation are given on pages 52 to 60.

GROUP II

9. Bolt and Washer Assembly—A bolt and washer assembly operation was taken from a mid-west manufacturing concern. The ⅜″ x 1″ bolt was fitted with three washers as shown in Fig. 7.

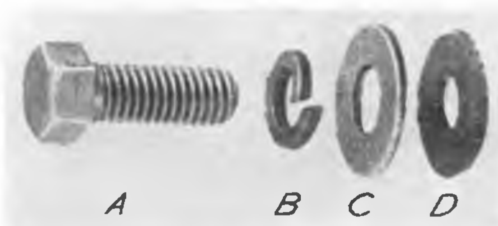

FIG. 7. Bolt and washer assembly. A—⅜″ x 1″ bolt; B—lock washer; C—plain steel washer; D—special rubber washer.

A simple fixture was made of wood and surrounded by metal bins of the gravity feed type as shown in Fig. 8. The bins containing the washers were arranged in duplicate so that both hands could move simultaneously, assembling washers for two bolts at the same time. As seen from Fig. 8 bins No. 1 contained the rubber washers, bins No. 2 the plain steel washers, bins No. 3 the lock washers and bin No. 4, located in the center of the fixture, contained the bolts.

Two countersunk holes or recesses were made in the front of the fixture into which the three washers fitted loosely, the rubber washer on the bottom, the plain steel washer next, and the lock washer on top. A small hole slightly larger than the diameter of the bolt went through the fixture. A metal chute was placed around the front of the wood fixture with openings to the right and the left of the two recesses so that assembled bolts and washers might be dropped into the top of this chute and carried down under the bench to a container.

In assembling the bolt and washers the two hands moved simultaneously toward the duplicate bins No. 1, each grasped a rubber washer which rested on the wood fixture in front of the bins and slid the rubber washers into place in the two recesses in the fixture. The two hands, then, in a similar way, slid the steel washers

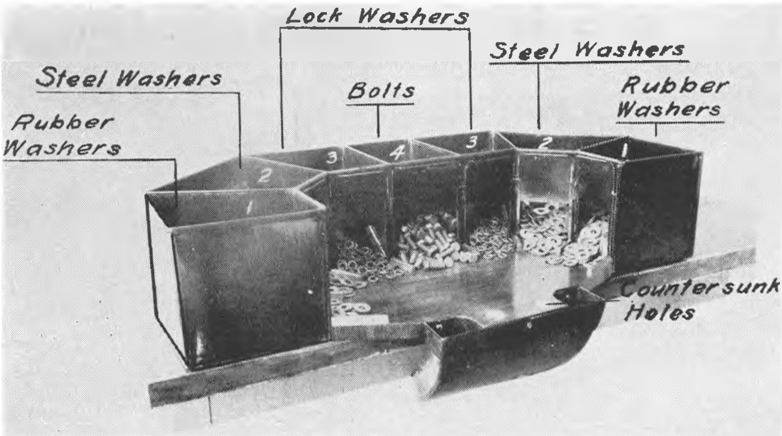

FIG. 8. Arrangement of work place for bolt and washer assembly.

into place on top of the rubber washers, and then the lock washers were slid into place on top of these. The hands then each grasped a bolt and slipped it through the washers which were lined up so that the holes were concentric. The hole in the rubber washer was slightly smaller than the outside diameter of the threads on the bolt so that when the bolt was forced through the hole the rubber washer gripped it and thus permitted the bolt with three washers to be withdrawn vertically upward without losing the washers. Simultaneously the two hands released these assemblies over the metal chute. As the operator began the next cycle with the hands in this position the second finger of each hand was in position to reach for the rubber washer which was almost at the tip of the finger.

Approximately .11 of a minute was required to make two assemblies using the method described above.[1]

10. Operator Studied—Due to the necessity of training the operator to perform this operation for the "slide" *grasp* and the "carry" *grasp* only one operator, A2, was used in this investigation.

The results of the studies made of operator A2 performing the bolt and washer assembly are given on page 32.

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[1] For a detailed motion analysis of the Bolt and Washer assembly see "Motion Study for Small Assembly," Ralph M. Barnes, *American Machinist*, Vol. 77, No. 11, p. 338-340, May 24, 1933.

V. INVESTIGATION NO. 1

A Study of the Time Required for Hand Motions of Varying Lengths

11. Object—The object of this investigation was to determine the time required for operators to move the hand empty and loaded through varying distances.

12. Procedure—The link forming operation was used in these studies and it is described in detail on pages 16 to 19. The two elements considered were: Element A—Transport Empty and Element D—Transport Loaded.

The material was carefully placed on top of the bench at varying distances from the center of the fixture as shown in Fig. 5. In each of the six studies care was taken to see that each piece of material lay flat on top of the bench. However, the pieces were not arranged in order and they were not placed at fixed distances from each other.

Studies C17 and C20 were made with the material placed at a distance of 8 inches from the center of the fixture. Before the motion pictures were made the operator was asked to perform the operation with the material placed at this distance for a while in order to become accustomed to it. Then motion pictures were made of this set-up. The analysis of this film (Studies No. C17 and C20) is shown in Tables IX and XII in the appendix.

In a similar manner studies No. C18, C21, and C19, C22 were made with the material placed at 16 and 24 inches from the fixture, respectively. Data from these studies are shown in Tables X, XI, XIII and XIV in the appendix.

Element A—Transport Empty

Element A was the therblig *transport empty* performed by the right hand. The preceding motion ended as the right hand released the knob of the forming lever. The right hand then moved to the right, the arm being pivoted at the elbow for the shorter distances, and at the shoulder for the longer distances. The motion ended at the instant the fingers touched the material on top of the bench preparatory to grasping one piece.

It will be noted that the therblig began with the hand in motion since it was already swinging the forming lever to the right. The therblig ended with the hand in a still position. The eye preceded the hand as it moved to the right to grasp the piece of material. The therbligs *select* and *grasp* were considered together, no attempt being made to separate them.

ELEMENT D—TRANSPORT LOADED

Element D was the therblig *transport loaded* performed by the right hand. This motion began the instant the right hand lifted the piece of material from the bench top. The motion was completed as the hand carried the piece to the left and began to deposit it in the slot in the fixture. In this element the hand started from rest and came to rest as the therblig ended, while in element A the therblig began with the hand in motion and ended with the hand at rest. It will be further observed that in *transport loaded* the hand turned the piece of material in the proper direction for inserting it into the slot in the fixture as it was being transported.

13. Results—The complete results of these studies are given in Tables IX to XIV in the appendix. However, certain information has been taken from these data sheets and assembled in more compact form as shown below.

TABLE I

SUMMARY OF TIME REQUIRED FOR ELEMENT A—TRANSPORT EMPTY

Study No.	Operator No.	Distance in Inches	Time in Minutes Average	Mode	Maximum	Minimum
C17	A2	8	.0037	.004	.004	.003
C18	A2	16	.0035	.004	.004	.003
C19	A2	24	.0049	.005	.005	.004
C20	A1	8	.0037	.004	.004	.003
C21	A1	16	.0053	.005	.006	.005
C22	A1	24	.0066	.0065	.008	.006

TABLE II

SUMMARY OF TIME REQUIRED FOR ELEMENT D—TRANSPORT LOADED

Study No.	Operator No.	Distance in Inches	Time in Minutes Average	Mode	Maximum	Minimum	Average Velocity in Feet per Minute
C17	A2	8	.0040	.004	.004	.004	166.7
C18	A2	16	.0057	.006	.006	.005	233.1
C19	A2	24	.0059	.006	.007	.005	337.3
C20	A1	8	.0050	.005	.005	.005	133.3
C21	A1	16	.0070	.006	.010	.006	190.5
C22	A1	24	.0080	.008	.012	.006	250.0

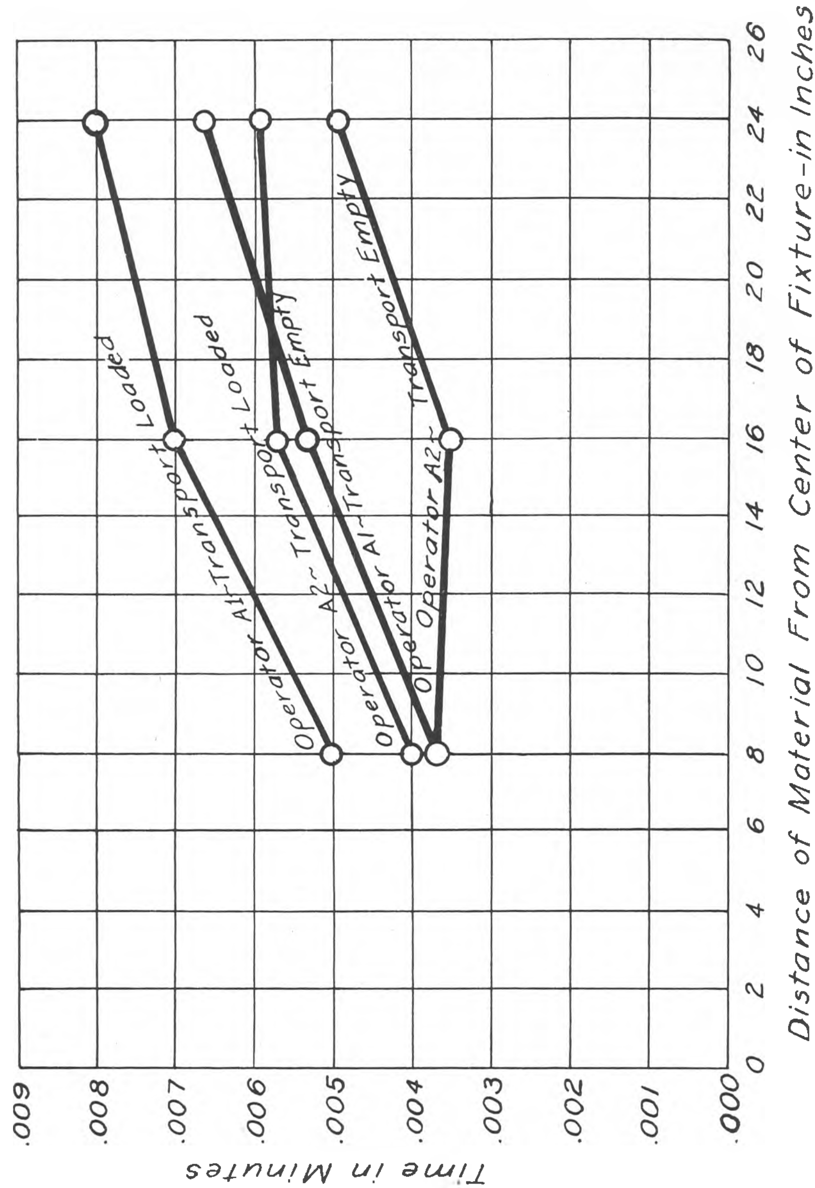

FIG. 9. Curves showing the time required to move the hand through distances of varying lengths.

Since the right hand in element D moved from a definite place on the bench to a definite place on the fixture and since the distance through which the hand moved was known, it was possible to find the average velocity of the hand motion by dividing the distance traveled by the time in minutes. This is not an absolute value because the hand moved through a curved path rather than in a straight line. However, the results are of value for making comparisons of velocities of short and long motions.

TABLE III

AVERAGE TOTAL TIME REQUIRED BY THE TWO OPERATORS TO FORM LINK

Study No.	Operator No.	Distance in Inches	Average Total Time per Cycle in Minutes	Operator A1 Required More Time Than A2 to Form Link
C17	A2	24	.0677	A1 5% more than A2
C20	A1	24	.0712	
C18	A2	16	.0630	A1 28% more than A2
C21	A1	16	.0808	
C19	A2	8	.0596	A1 38% more than A2
C22	A1	8	.0823	

14. Conclusions—The results of this particular investigation seem to indicate that:

1. It requires a slightly greater period of time to move the hand through a long distance than through a short distance, all other conditions being constant. This is shown by the data to be true in both *transport empty* and *transport loaded.* Fig. 9 illustrates this graphically. The work[1] of other investigators seems to verify our results on this point.

[1] Freeman, F. N., "Analysis of the Writing Movement," *Psychology Monographs*, Vol. 17, No. 4, December, 1914, p. 1-46.

Stetson, R. H., "A Motor Theory of Rhythm and Discrete Succession," *Psychology Review*, Vol. 12, No. 4, No. 5, July and September, 1905, p. 250-270 and p. 293-350.

Kries, J. V., "Zur Keuntniss d. willk. Muskelthätigkeit," *Archiv f. Physiologie,* 1881, Suppl. I.

Freeman, F. H., "Preliminary Experiments on Writing Movements," *Psychology Monographs*, Vol. 8, No. 3, June, 1907, p. 301-333.

Woodworth, R. S., "The Accuracy of Voluntary Movement," *Psychology Monographs*, Vol. 3, Whole No. 13, July, 1899, p. 1-114.

Dresslar, F. B., "Some Influences which Affect the Rapidity of Voluntary Movements," The *Amer. Journal of Psychology*, Vol. 4, No. 4, August, 1892, p. 514-527.

Bryan, Wm. L., "On the Development of Voluntary Motor Ability," *The Amer. Journal of Psychology,* Vol. 5, No. 2, November, 1892, p. 125-204. Bryan states, "It has been shown by Von Kries and confirmed by myself that variations in the amplitude of movement within wide limits do not affect the rate. This paradox,—which I have found to hold also for the eye movements within the angle of usual movement, is due to one or both of the following causes. For small distances, and especially for distances less than those usually passed over, the time of arrest, reversal, and of passing through the space

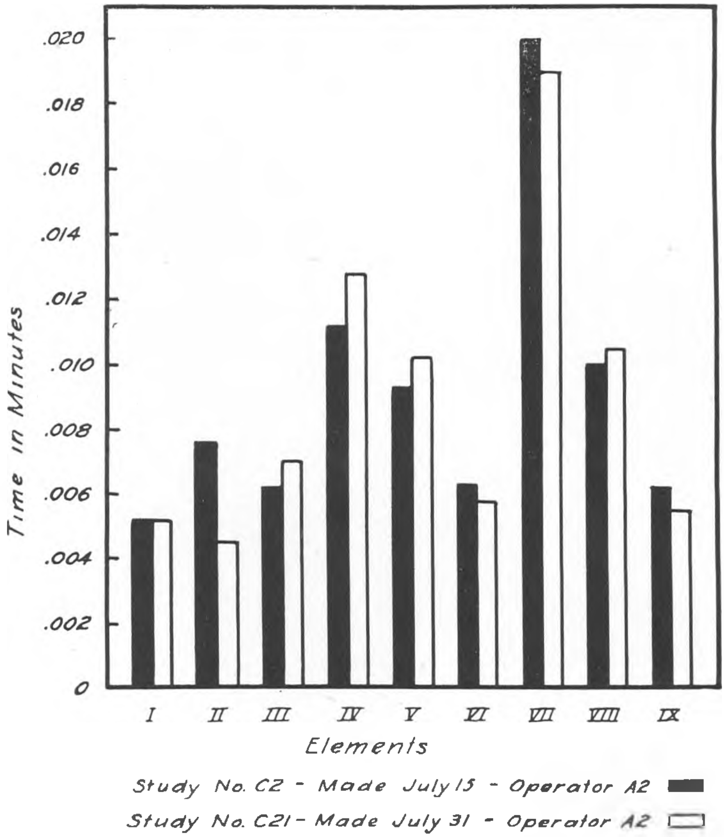

FIG. 10. Chart showing the average time required by the same operator to perform each of the elements in the cycle on July 15, and then on July 31.

2. The average velocity of the hand is greater for the longer motions than for the shorter ones. Table II shows this to be the case. The maximum average velocity of 337.3 feet per minute was attained by operator A2 when moving the hand through a distance of 24 inches.

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nearest the points of reversal, may be slightly increased. In all cases the sum of these times must be so great in proportion to the time occupied in passing through the middle space that a slight increase in the latter is inappreciable. That is to say, the rate of tapping is almost identical with the rate of voluntary arrest and reversal." p. 199.

The data on which the above writer based his conclusions are given below. The operation is that of tapping a telegraph key.

Extent of Excursion in mm.	1	5	10	15	20	25	30	40
Ave. Number of Double Excursions in 5 seconds.	26.0	28.8	28.4	29.6	30.0	29.4	25.0	23.2

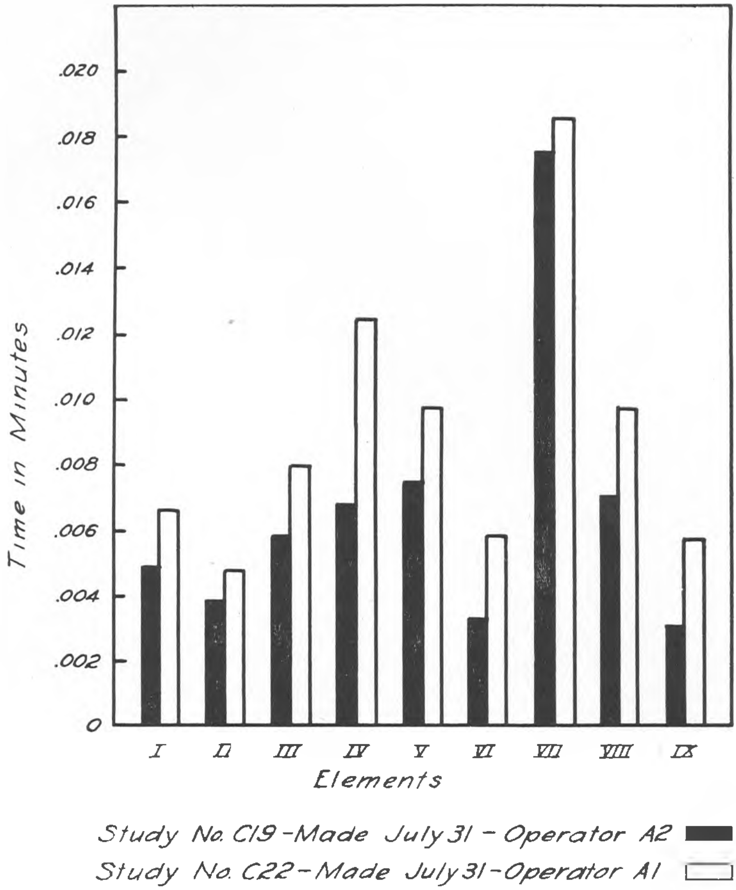

FIG. 11. Chart showing, element by element, the superior performance of operator A2 over operator A1.

3. The time required to *grasp* the piece of material is not greatly affected by the distance through which the hand moves in either the therblig preceding or following the *grasp*.

4. There is a very high degree of consistency in the time required by an expert operator to perform identical therbligs in the same operation even though a considerable length of time (two weeks in some of our studies) may have elapsed between different performances. Fig. 10 shows the differences in the average time required by the same operator to perform each of the elements

in the cycle on July 15, and then on July 31. The first studies required an average time of .0823 minute while the studies made on the later date required .0808 minute. Operator A2 was more consistent than operator A1.

5. There was a very decided difference in the speed of performance of the two operators studied. Operator A2 formed the link at a much faster rate than did operator A1. Fig. 11 shows element by element the superior performance of operator A2. Table III also brings out this point. Studies No. 17 to 22 inclusive were made on the same day.

VI. INVESTIGATION NO. 2

A Study of the Time Required for Performing the Motion Grasp Under Various Conditions

15. Object—The object of this study was to determine the time required to grasp[1] a piece of material used in the link forming operation, the *grasp* being made in three different ways as follows:

1. Pressure-grasp[2]—material horizontal and not prepositioned.
2. Full-hook grasp[3]—material vertical and prepositioned.
3. Full-hook grasp—material horizontal and prepositioned.

16. Procedure—In study No. X51 the material was placed on a mat at a distance of 10 inches from the center of the fixture. The material was scattered about on the mat but care was taken to see that the pieces were not tangled up with each other. They were not, however, arranged in an orderly or even pattern on the mat.

In study No. X52 the material was placed vertically in small holes drilled in a block of wood as shown in Fig. 12. The holes were spaced at ½ inch intervals in one direction and at one inch intervals in the other direction. The first row of material was 10 inches from the center of the fixture.

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[1] In this investigation no attempt was made to separate therbligs *select* and *grasp*. These two therbligs will be referred to here as *grasp*. In the link forming operation *grasp* began at the end of the therblig *transport empty* and ended at the beginning of the therblig *transport loaded*.

[2] "Pressure grasp" as in grasping a pencil lying flat on the table top.

[3] "Full-hook grasp" as in grasping a pencil lying on the table with one end raised an inch or so, so that the thumb and fingers are able to (hook) grasp by reaching around the pencil instead of grasping by pinching.

FIG. 12. Material placed vertically in holes in wood block.

In study No. X53 the material was placed horizontally in grooves one half inch apart in a wood block as shown in Fig. 13. The first row of material was 10 inches from the center of the fixture.

Operator A2 performed all of the operations for these three studies. She was allowed to practice on each set-up before pictures were made of the operation. All three studies were made with the motion picture camera operating at a speed of 2000 frames per minute.

17. Results—The results of this investigation are given in detail in Tables XV, XVI and XVII in the appendix. The time required for the operator to grasp (Elements B and C) a piece of material is summarized in the table below.

TABLE IV

Study No.	Position of Material	Time in Minutes Required to *Grasp*			
		Av.	Mode	Min.	Max.
X51	Horizontal on mat	.00558	.0050	.0040	.0110
X52	Vertical in holes	.00279	.0025	.0020	.0055
X53	Horizontal in grooves	.00225	.0020	.0020	.0030

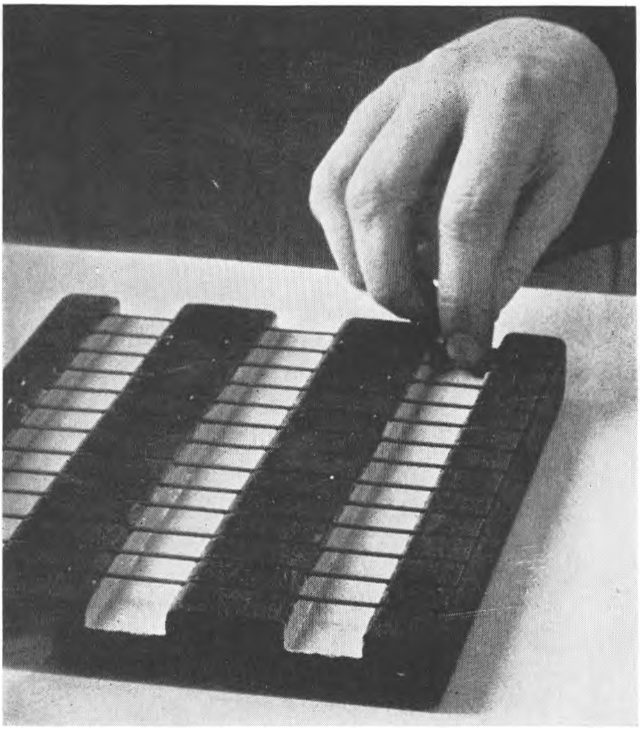

FIG. 13. Material placed horizontally permitting a "full-hook grasp."

18. Conclusions—1. The time required to *grasp* a piece of material is shorter when the material is prepositioned and arranged so that a full-hook grasp can be used. The data show that it required twice as much time to *grasp* the piece of material when it rested flat on the mat than when it was picked up with a full-hook *grasp*.

2. There was a slight difference between the time required to *grasp* the material in the vertical position and in the horizontal position, a full-hook *grasp* being used in both cases. The horizontal position permitted a slightly faster grasp. This seems logical since in grasping the piece of material in the vertical position the thumb and the first finger had to slip down one half to three quarters of an inch over the end of the piece, while in the case where the material was placed horizontally the piece was

grasped with lesser movement of the thumb and finger and consequently required a shorter time.

3. The time required for the motion *transport loaded* which followed the *grasp* therblig was slightly greater when the material was grasped in the vertical position than when grasped in the horizontal position. Since the piece of material was inserted into the slot in the fixture in the horizontal position it was necessary for the operator to turn the piece of material from the vertical to the horizontal position in transporting it to the fixture in the first case. This positioning may have slowed down the *transport loaded* therblig.

VII. INVESTIGATION NO. 3

A Study of the Time Required to Transport Small Objects Through a Short Distance (A) by Sliding and (B) by Carrying

19. Object—The object of this study was to compare the time required to move a small object from one place to another by sliding it and by carrying it. This involved the measurement of the two therbligs *grasp* and *transport loaded*.

20. Procedure—The operation of assembling the three washers on to the bolt as described on page 20 was used for this study. For the first study, X74, the fixture shown in Fig. 8 was altered by placing a partition made of wood one half inch high in front of each of the seven compartments. This made it necessary for the operator to *grasp* a piece of material and *carry* it to the point of assembly instead of *sliding* it into place in the fixture.

A second series of studies (X75) was made in the same manner as those in X74 except that the wood partition was removed and the operator was able to *slide* the rubber washers, steel washers and lock washers into place for the assembly.

Operator A2 performed the operations for both of these studies. She was allowed to practice on each set-up before pictures were made of the operation. Both studies were made on the same day under identical conditions with the exception of the partition in study X74.

The motion pictures of this operation were made with the hand cranked camera at high speed using the "slow-motion" attachment.

Time was indicated on the film by the microchronometer geared to read directly in 5000ths of a minute. Because of the extensiveness of data obtained only a summary will be included here.

21. Results—

TABLE V

TIME REQUIRED TO GRASP AND TRANSPORT A SMALL OBJECT THROUGH A SHORT DISTANCE

	Time in Minutes for *Grasp*		*Transport Loaded*	
	X74 Carry	X75 Slide	X74 Carry	X75 Slide
Rubber Washer	.00960	.00033	.00690	.00640
Steel Washer	.00895	.00031	.00530	.00896
Lock Washer	.00750	.00038	.00855	.00711

	Time in Minutes for *Grasp* plus *Transport Loaded*	
	X74 Carry	X75 Slide
Rubber Washer	.01650	.00673
Steel Washer	.01425	.00927
Lock Washer	.01605	.00749

22. Conclusions—1. It required approximately twice as long to *grasp* and *carry* the washers as it did to *grasp* and *slide* them. The therblig *transport loaded* required about the same length of time in both cases but the *grasp* preceding the *carry* required 20 to 30 times longer than did the *grasp* preceding the *slide*.

2. Studies X74 and X75 were carried out in exactly the same manner with the exception of the two therbligs *grasp* and *transport loaded,* yet the average time required for the cycle in study No. X74 was .1329 minute while the average time for study No. X75 was .1092 minute. This shows an appreciable saving on the entire operation in favor of the movement of the washers by sliding.

VIII. INVESTIGATION NO. 4

A STUDY OF THE CONSISTENCY OF THE MOTION PATHS MADE BY THE HAND

23. Object—The object of this study was to determine the consistency with which the hand followed the same path in a given operation.

24. Procedure—The first eight consecutive cycles of the link forming operation in study No. X53 were analyzed graphically in order to find the path traveled by the right hand in the motions *transport empty* and *transport loaded.*

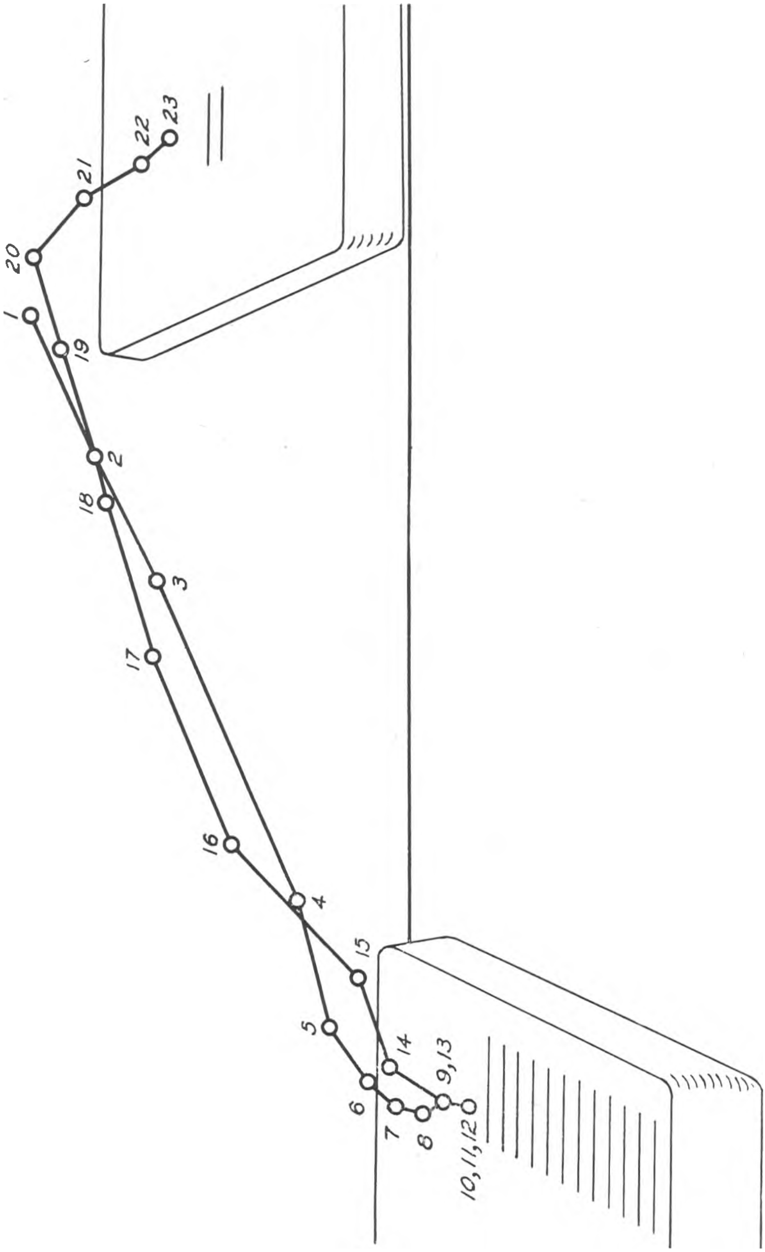

FIG. 14. Motion path of index finger of right hand for therbligs *Transport Empty*, *Grasp* and *Transport Loaded* in the link forming operation. Study No. X53, cycle No. 1.

The film was projected on a white sheet of paper, one frame at a time, and each successive position of the center of the index finger nail of the operator's right hand was marked on the paper and numbered consecutively. In Fig. 14 for example, the points are numbered from one to twenty-three inclusive. Since the film was exposed at the speed of 2000 frames per minute, the time interval from one frame to the next—or from one point to the next in Fig. 14—was 1/2000th of a minute.

In analyzing the film the projector was placed at such a distance from the screen (sheet of white paper) that the path of the right hand was full scale. Starting with the place where the right hand just came even with the right side of the fixture, the position of the center of the index finger nail was marked 1, the next frame of the film was then projected and the position of the center of the index finger nail was marked 2, and so on. When the hand came to an absolute standstill in grasping the piece of material, the numbers were marked on the sheet of paper as the frames were projected although no movement of the finger occurred. This accounts for the zeros which are recorded on the data sheet in Table VI.

In a similar manner the path for the therblig *transport loaded* was marked on the sheet of paper and each point was numbered until the piece of material was deposited in the slot of the fixture and the motion of the fingers came to a standstill.

After the points had been located on the sheet of paper, it was removed from the screen and straight lines were drawn connecting the points. Then these distances were measured in millimeters and the readings were recorded on the data sheet Table VI.

25. Results—In study No. X53, Cycle No. 1 (See Table VI) the operator moved her index finger 33 mm. in going from point 1 to 2. This movement required 1/2000ths of a minute. It required 22/2000ths of a minute for the finger to move from point 1 to point 23. That is, it required 22/2000ths of a minute for the therbligs *transport empty*, *grasp* and *transport loaded*. The total corrected distance[1] moved in *transport empty* was 192 mm.—the total distance for *transport loaded* was 224 mm.

[1] An attempt was made to begin to number the hand movements at the same point in each of the eight cycles. The frame showing the position of the hand nearest the right edge of the fixture was taken as number 1 in each cycle. As Fig. 15 shows, point number one did not always fall exactly at the same position relative to the edge of the fixture

TABLE VI

MOVEMENTS OF THE RIGHT HAND IN TRANSPORT EMPTY AND TRANSPORT LOADED IN THE LINK FORMING OPERATION

STUDY NO. X53

Points	Cycle No. 1	2	3	4	5	6	7	8
	Distance in Millimeters from One Point to the Next							
1– 2	33	42	25	27	31	44	28	19
2– 3	29	37	46	31	39	60	38	32
3– 4	74	50	46	40	43	55	62	64
4– 5	28	36	44	56	50	41	46	58
5– 6	14	8	32	30	31	14	39	41
6– 7	8	7	19	12	24	10	20	15
7– 8	6	11	10	9	15	4	7	12
8– 9	5	3	6	6	6	0	6	7
9–10	5	2	0	8	6	0	7	0
10–11	0	0	0	4	0	0	0	0
11–12	0	7	0	4	0	0	0	0
12–13	5	11	0	0	0	0	0	0
13–14	9	9	6	0	0	7	0	0
14–15	20	29	11	11	0	25	7	6
15–16	39	37	19	20	6	33	8	11
16–17	44	34	34	28	10	41	18	11
17–18	34	43	43	46	19	41	41	25
18–19	34	37	48	41	11	39	42	38
19–20	21	15	38	38	40	29	39	52
20–21	11	14	29	36	62	22	41	48
21–22	9	18	18	12	41	17	23	38
22–23	8	11	15	14	34	20	29	24
23–24	0	5	10	11	19	13	21	22
24–25		0	0	8	16	0	14	18
25–26				5	9		9	7
26–27				0	0		0	0
Corrected Total Distance for *Transport Empty*	192	196	204	199	215	225	232	231
Total Distance for *Transport Loaded*	224	270	272	270	267	287	292	300

Although the path for each cycle was made on a separate sheet of paper such as the one shown in Fig. 14, the first five motion paths have been superimposed one upon another as shown in Fig. 15. This makes it possible to tell at a glance how the motion paths varied.

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so a correction for this was made. This correction factor was the distance subtracted from the path of motion in order to bring all eight cycles to the same starting place.

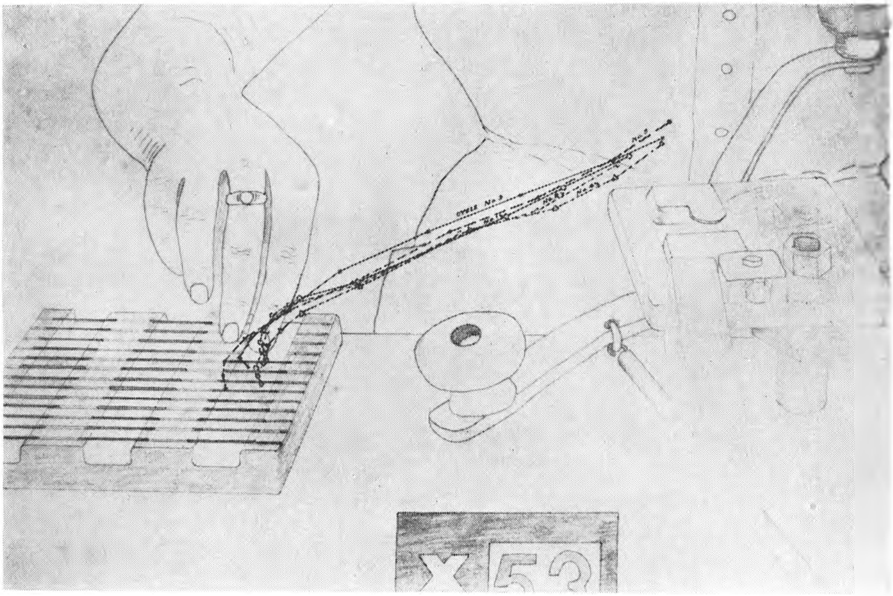

FIG. 15. Motion paths of index finger of right hand for five consecutive cycles. Link forming operation. Therblig *Transport Empty*. Study No. X53, cycles No. 1 to 5 inclusive.

The sum of the distances in millimeters between points on the figure indicates the total length of the path made by the finger. There is some slight error here since the finger did not move in straight lines from one point to the next, but rather in a smooth curved path. Furthermore, there was a slight horizontal component which is not shown by the motion paths. These, however, are not great errors.

26. Conclusions—1. The paths made by the index finger of the right hand in the five consecutive cycles of *transport empty* were very close together (See Fig. 15). It may be said of this operator that she tended to move her hand through almost identically the same path, in two dimensions, in going from one point to another.

2. An average speed of 133.6 feet per minute was made by the operator's right hand in the therblig *transport empty* in cycle No. 1. The maximum instantaneous speed between any two points in the motion paths studied was 550 feet per minute. This occurred between points 3 and 4 in cycle No. 1. (See Fig. 14).

PART II

A STUDY OF HAND MOTIONS USING THE PRINCIPLE OF THE KYMOGRAGH

IX. INVESTIGATION OF THE MOTION OF THE RIGHT HAND—TRANSPORT LOADED, STOP AND CHANGE DIRECTION

27. Object—The object of this investigation was to discover and measure the component parts of the motions of the right hand—*transport loaded* (away from the body), *stop* and *change direction*, and *transport loaded* (toward the body).

28. Equipment Used in Making the Studies—While the micromotion study technique is quite satisfactory for most kinds of investigations of hand motions in industry[1] it is not entirely satisfactory for studies requiring the greatest precision. In order to make even a fairly accurate measurement of rapid hand motions the film must be exposed at a rate of 2000 to 4000 frames per minute. When this is done the cost of the film is almost prohibitive for long investigations and furthermore the time required to analyze the film is excessive.

Since the main purpose of this investigation was to study the behavior of the hand in making some simple movements it was apparent that the first requirement was a device capable of measuring and recording movements of very short duration—as short as 1/1000th of a second.

After considering a number of different methods for recording and analyzing hand motions, the method using the principle of the kymograph was selected as being the most suitable. Apparatus was constructed to utilize the principle of recording hand motions on the surface of a sheet of paper moving at a uniform and known velocity across a table top.

The apparatus, in its final form, is shown in Fig. 16. Newspaper print was drawn from a supply roll across the top of the table between two rollers. The bottom roller was driven by a synchronous motor through a chain of gears. Friction as well

[1] For bibliography on time and motion study and related subjects see Bibliography at end of paper "The Motion Picture Camera in Time and Motion Study Research" by Ralph M. Barnes, *International Review of Educational Cinematography*, Vol. 5, No. 6, p. 412-35, June, 1933.

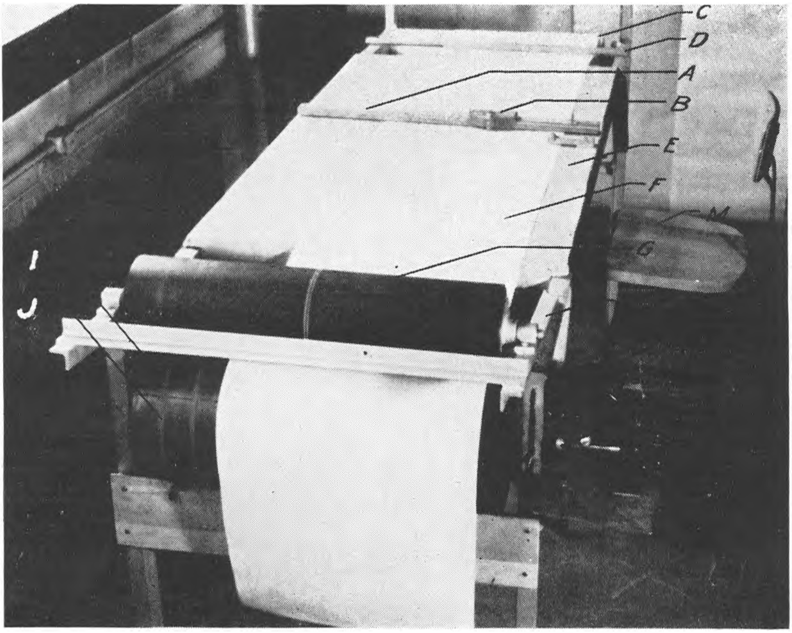

FIG. 16. Apparatus for recording and timing movements of the hand. A—Oak slide; B—pencil carriage; C—supply roll of news-print paper; D—guide for paper; E—table top; F—paper; G—idle roller; H—hinged angle iron frame carrying idle roller; I—drive roller; J—heavy rubber bands glued to drive roller; K—synchronous electric motor; L—gear drive; M—adjustable chair for subject.

as small sharp teeth projecting radially from the bottom roller prevented the paper from slipping.

The bottom or drive roller rotated at a constant speed of 60 R.p.m. Its effective circumference was 31.9 inches consequently the peripheral speed of the roller, and also the speed of the paper, was 31.9 inches per second. A special scale was made with 100 divisions to 3.19 inches, therefore, one division or .0319ths of an inch equalled one thousands of a second. As distances of three hundredths of an inch can be easily read with the naked eye, the actual readings could be made to at least the nearest 1/1000th of a second.

29. Principle of Operation—If a paper moves with constant velocity across a table, and if a pencil point is drawn across the paper in a direction perpendicular to the path of the paper, the

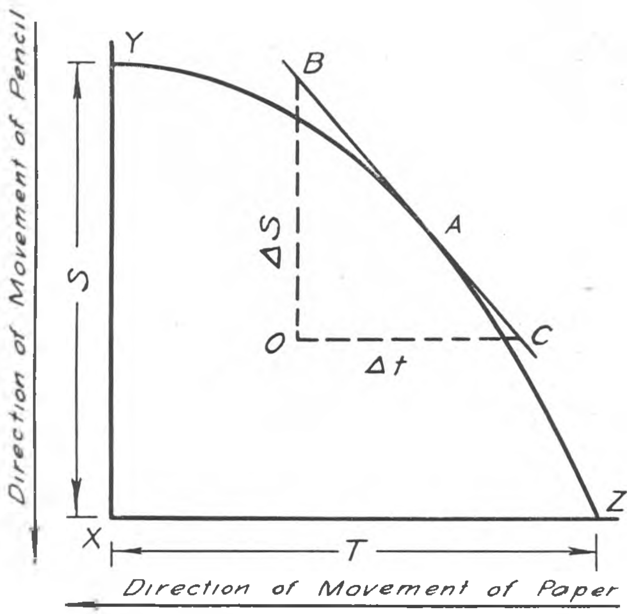

FIG. 17. Curve resulting from the movement of a pencil point across a moving band of paper.

resulting mark will be a space-time curve. That is, the slope of the curve thus generated at any point will be the velocity of the pencil point at that point. This may be demonstrated thus: Let YZ in Fig. 17 be the actual curve made by the pencil point traveling from Y to X across the paper, while the paper is moving at (V_c) constant velocity across the table from right to left. Let BC be the tangent to the curve YZ at any point A on the curve. Then the slope of the curve YZ at the point A=OB/OC. But OB/OC= $\triangle S / \triangle t$, then as $\triangle S / \triangle t = V_i$, ($V_i$=instantaneous velocity) OB/OC=V_i.

The horizontal distance T between Y and Z equals the total time for the pencil point to travel the vertical distance S. Thus the average velocity V while traveling the total distance S in the time T is S/T, or V=S/T.

30. Hand Movements Studied—The first investigation[1] made with the above apparatus was of a controlled "back and forth"

[1] The investigation reported on the following pages is an abstract of a Master's thesis by Wayne J. Deegan, "The Development and Use of a New Technique for Measurement in Time and Motion Study." The State University of Iowa, 1935.

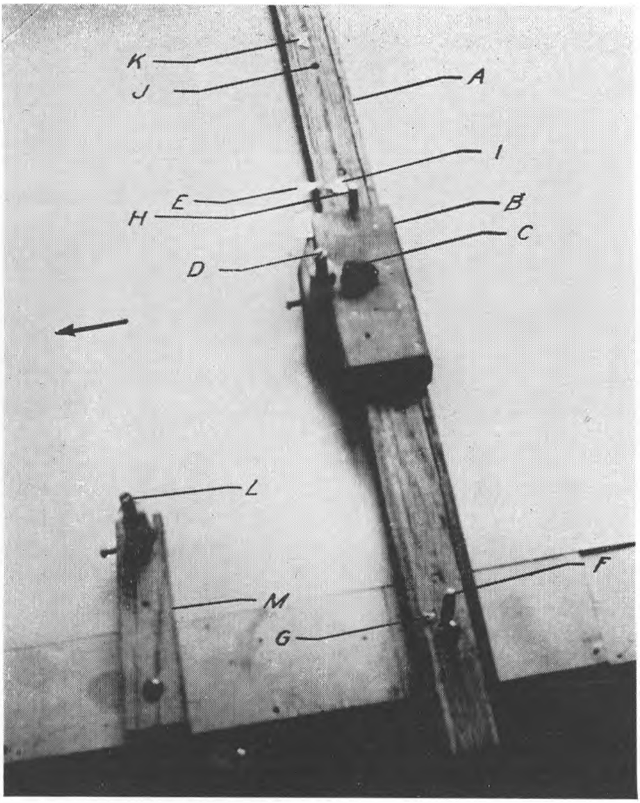

FIG. 18. Slide assembly. A—oak slide; B—pencil carriage; C—button for operator to hold; D—adjustable lead pencil; E—pointer on pencil carriage to match marks on slide; F—base pin stop; G—base mark for visual stop; H—outer pin stop at 5″; I—outer mark for visual stop at 5″; J—hole for pin stop at 10″; K—outer mark for visual stop at 10″; L—adjustable lead pencil for making base line; M—pencil anchor.

motion of the right hand directly away from and toward the operator. The cycle was as follows: Having grasped the button C on top of the carriage (See Fig. 18) with the thumb and index finger of his right hand the operator moved the carriage back and forth on the slide between the stops.

The following variables were introduced:

1. Direction of motion
   A. Away from operator

B. Toward operator
C. Stop and change direction

2. Hand travel
   A. 5″
   B. 10″
   C. 15″
3. Kind of stop at end of motion
   A. Mechanical, that is, a positive stop of the carriage against the pin in slide
   B. Visual, that is, matching the mark on the carriage with the mark on slide

The carriage bearing a pencil point was fitted to move on a slide in order to restrict the hand motion. This permitted the investigator to hold all conditions constant except the one being studied. The slide, in the form of an oak bar, was fastened at each end of the table top with clearance for the paper to pass under it. The carriage was moved back and forth along this slide.

31. Procedure—After the preliminary work was completed four things were clearly shown by sample curves that had been obtained. These curves showed that in every motion of the hand there was a definite period of acceleration, of constant velocity, of retardation or deceleration, and of changing direction. The period of acceleration or deceleration was shown by a curved line, the period of constant velocity by a straight inclined line and the period of changing direction by a straight horizontal line. (See Fig. 20) With this in mind data sheets were made to record the essential information concerning each curve. For simplicity certain symbols were adopted. The graphical representation of these symbols is shown in Fig. 20 and the definitions are given below.

The six different types of motion indicated by the symbols 1A, 2A, 3A, and 1B, 2B, 3B were obtained as follows:

For type 1A, 2A, 3A:

The operator moved the carriage (B), in Fig. 19, at normal speed back and forth on the slide (A) between the base pin stop (F) and the outer pin stop, which was spaced to allow the desired length of movement of the carriage. This motion was designated as MS–M–RC, that is, it was movement on a slide with mechanical stops and was repetitive and continuous.

TABLE VII

DEFINITIONS OF SYMBOLS

		Units	Symbols
	"S" = Distance		
1.	Total movement of hand	inches	A
2.	Length of motion at constant velocity (i.e., on plateau)	"	S_p
3.	Length of motion during acceleration	"	S_a
4.	Length of motion during retardation or deceleration	"	S_d
	"T" = Time		
5.	Time to travel distance S	seconds	T
6.	Time to change direction (i.e., zero velocity)	"	T_o
7.	Time to travel distance S_p	"	T_p
8.	Time to travel distance S_a	"	T_a
9.	Time to travel distance S_d	"	T_d
	"V" = Velocity		
10.	Av. velocity through ½ cycle (S/T)	in./sec.	V
11.	Av. velocity along plateau (S_p/T_p)	"	V_p
12.	Operator		O
	Parts of Curves		
13.	Complete cycle (i.e., from the time the hand starts away from the body until it is again ready to start away from the body)		C
14.	Part of cycle in which movement is toward operator		T
15.	Part of cycle in which movement is away from operator		A
	Types of Motions		
16.	Movement on slide		MS
17.	Free motion (i.e., no slide)		MF
18.	Movement against mechanical stops (suffix)		M
19.	Movement against visual stops (suffix)		V
	(Thus MS–M means movement on slide with mechanical stops)		
20.	Repetitive continuous motions (suffix)		RC
21.	Repetitive discontinuous motions (suffix)		RD
22.	Non repetitive motions (suffix)		RN

Curve Identification

Curve Type	*Distance*	*Identification Symbols*
1A	5″	MS–M–RC
2A	10″	MS–M–RC
3A	15″	MS–M–RC
1B	5″	MS–V–RC
2B	10″	MS–V–RC
3B	15″	MS–V–RC

For type 1A, the movement was limited to five inches by means of the stops. For type 2A, the movement was ten inches and for type 3A fifteen inches.

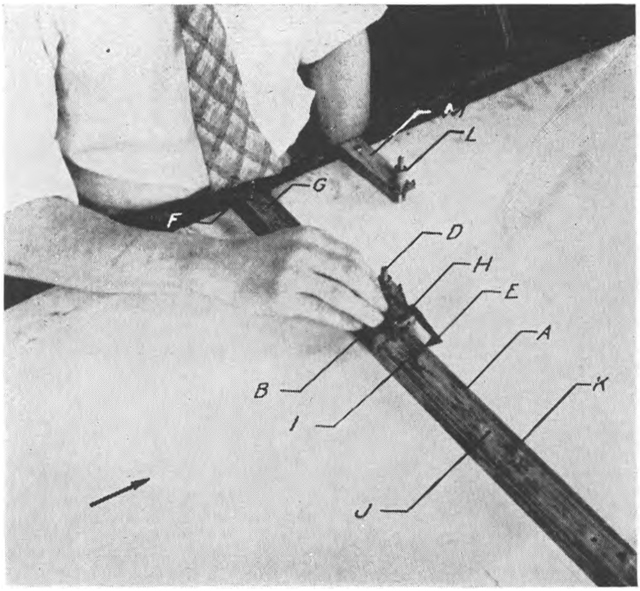

FIG. 19. Operator seated at table in position to move slide. A—oak slide; B—pencil carriage; D—adjustable lead pencil; E—pointer on pencil carriage to match marks on slide; F—base pin stop; G—base mark for visual stop; H—outer pin stop at 5″; I—outer mark for visual stop at 5″; J—hole for pin stop at 10″; K—outer mark for visual stop at 10″; L—adjustable lead pencil for making base line; M—pencil anchor.

For type 1B, 2B, 3B:

The operator again moved the carriage on the slide through five-inch (1B), ten-inch (2B) and fifteen-inch (3B) distances. Again the motion was a movement on the slide, which was denoted by MS. The stops used for this type movement were visual, therefore, denoted by suffix (V). That is, instead of pushing the carriage against the stops as in types 1A, etc., the operator now limited his motion by matching the pointer (E), Fig. 19, on the carriage with the mark on the slide corresponding to the desired length of movement. The movement again was repetitive and continuous so that the complete designation of this type motion was MS–V–RC.

Data were taken for these six types of movements from the curves of the different operators. The elements T_a, T_p, T_d, T_o, T, S_a, S_p, S_d, and S were recorded for five cycles of each of the six different types of motion just described. Twenty-eight different subjects or operators were studied. Practically all of these were college students.

The actual test procedure and the method of analysis were as follows:

Before beginning a test a data sheet called "operators individual record" was filled out. This sheet was used to record essential information concerning the individual operator. When this had been done the principle of the machine and the object of the tests were explained and demonstrated to the operator.

The operator was then seated in the adjustable chair directly in front of and close to the machine (Fig. 19). His elbow height was regulated by raising or lowering the chair so that the point of his elbow was one inch above the table top when the operator's fingers were grasping the button on the slide which was against the five-inch stop. With these things satisfactorily adjusted each operator was instructed as follows:

"Let us suppose that you are a new employee of mine. The job you have to do is this. (The slide was then moved back and forth ten times to illustrate the operation.) You are to be paid for the number of times that you move this slide back and forth in a day. That is, you are to be paid piece rate. Now, I want you to work at the rate at which you think you would work under those conditions. Now practice this a few times. I will then start the machine and take samples of your movement."

The operator was allowed to move the slide for thirty complete cycles without the paper running under the slide. When the operator had done this, the machine was started and ten or twelve complete hand motions were recorded on the moving paper. The machine was then stopped and the operator was allowed to try a different type of motion for thirty cycles, and the same procedure was again followed. In all but three cases, types of the curves obtained from the operators were taken in the order 1A, 1B, 2A, 2B, and 3A, 3B.

32. Method of Analysis—The procedure followed in analyzing these curves consisted of two parts. The curves made by each operator were first analyzed and the data tabulated. After this was done the results for each and all the operators were studied and compared.

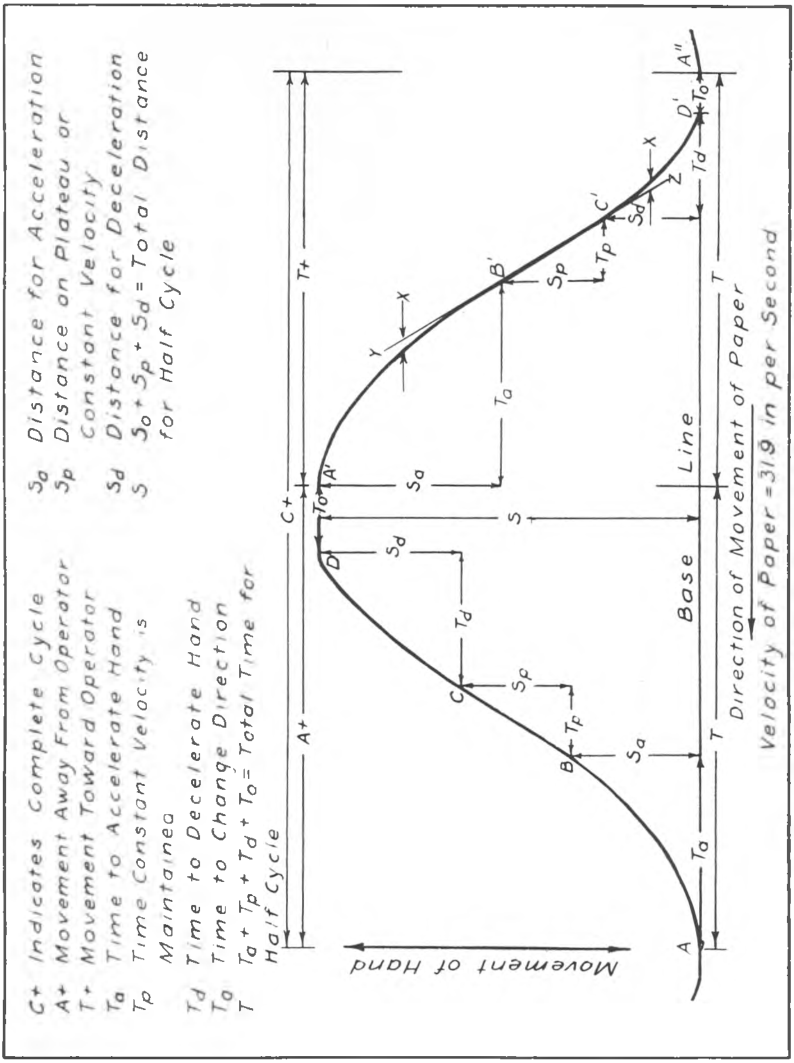

FIG. 20. Symbols and nomenclature used in the analysis of hand movements.

The sheet with the curve (See Fig. 21) to be analyzed was placed on a large drawing board and the base line was lined up with the straight edge which held the paper in place by its own weight. Another small straight edge was then fitted to the plateau to find the place where the curve varied from a straight line.

The points which marked the beginning and ending of the

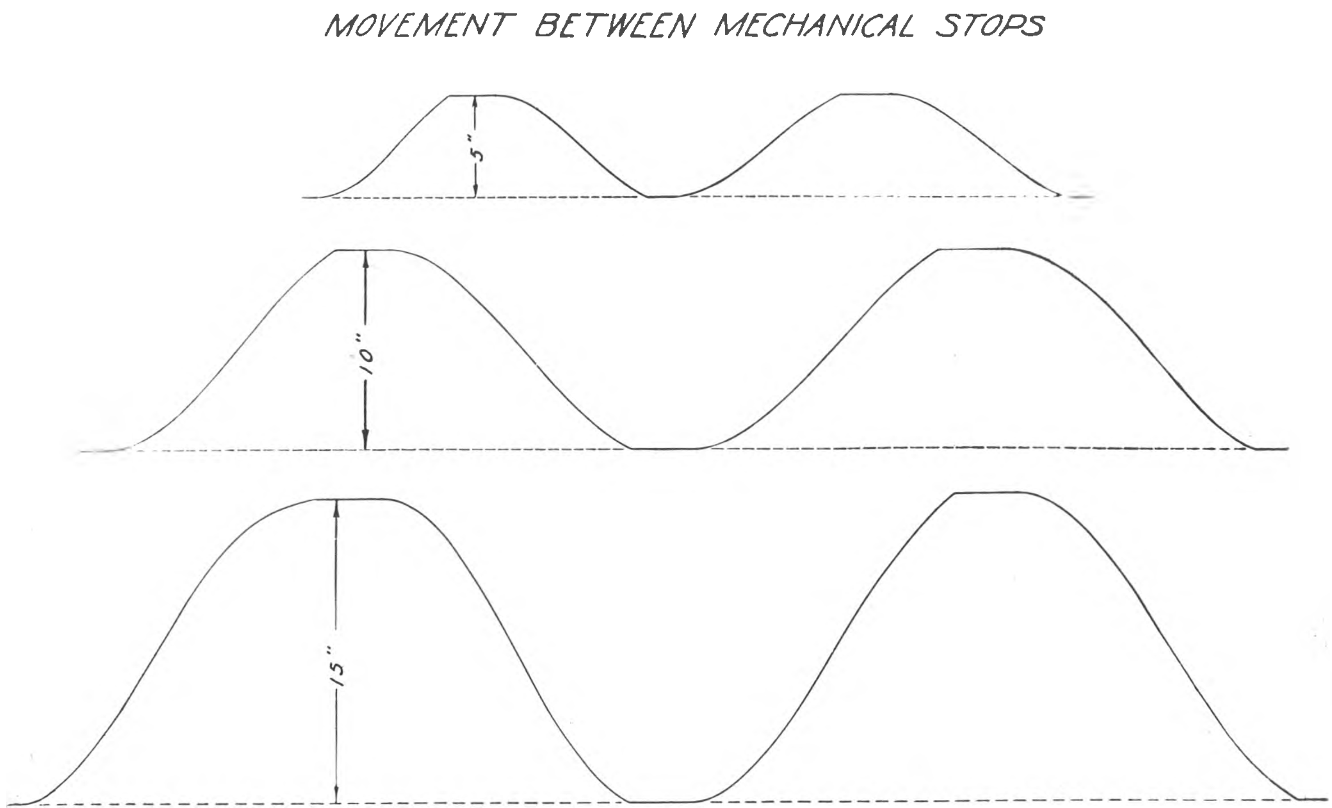

FIG. 21. Sample of actual curves made by operator No. 8.

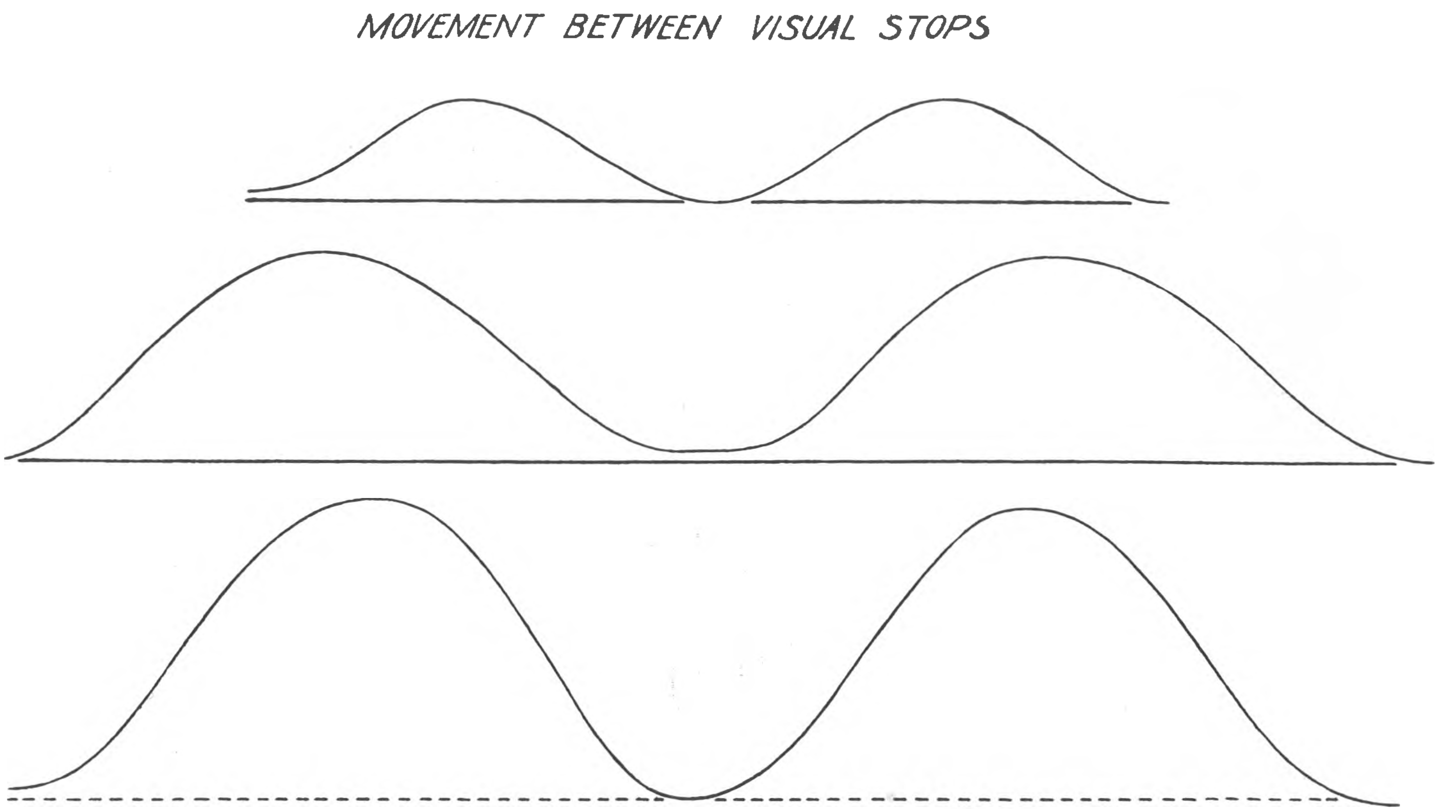

FIG. 21. Sample of actual curves made by operator No. 8.

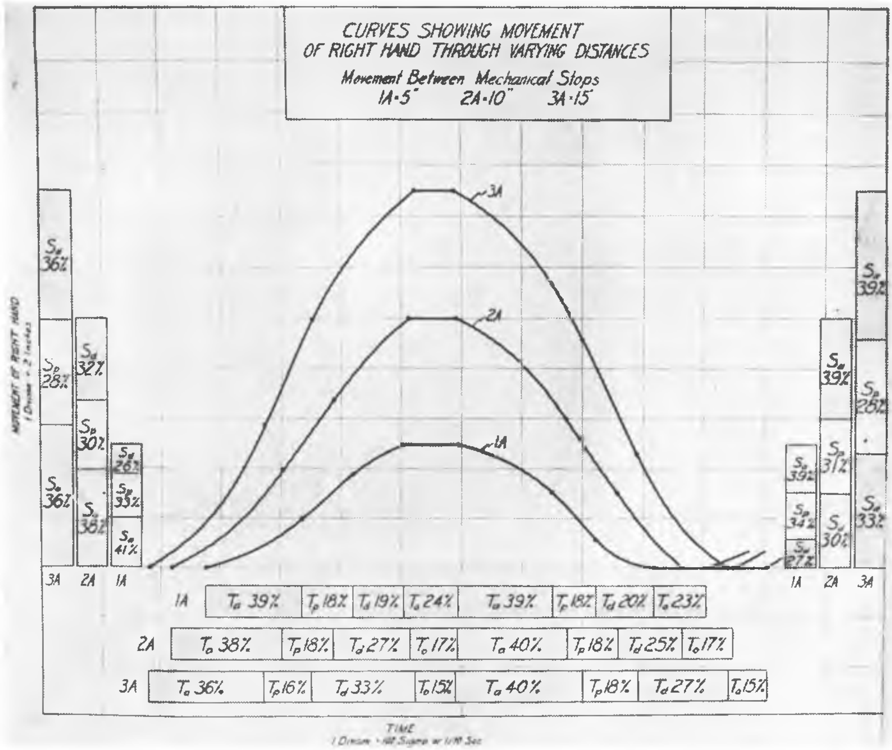

FIG. 22. Curves showing movement of right hand through varying distances—between mechanical stops.

elements were called critical points. These points were A, B, C, D, A_1, B_1, C_1, and D_1 in Fig. 20. The critical points B′ and C′ were chosen where the deviation (i.e., x) of the curve A′D′ from the straight edge YZ equalled 0.0005 sec. or ½ sigma. That is, the readings were taken to the nearest thousandth of a second. Using triangles the points B, C, D, A′, B′, and C′ in Fig. 20 were projected vertically to the base line AD′. The points B, C, B′ and C′ were projected horizontally on to the vertical scale. When this had been done all the elements of time for the curve were measured along the base line. Likewise all the elements of distance were measured along the vertical.

33. Results—After the data had been obtained and recorded in this manner for all the operators it was analyzed. A summary of the results is shown in Table VIII.

34. Conclusions—The following conclusions are based on the results of this investigation.

1. When the length of motion is doubled (from five to ten inches) the time required to make the motion is increased 15% for mechanical stops and 10% for visual stops.

2. When the length of motion is trebled (from five to fifteen inches) the time required to make the motion is increased 25% for mechanical stops and 22% for visual stops.

3. The total time, average velocity and maximum velocity increases almost as a straight line as the length of the motion increases from five to fifteen inches.

4. The ratio of the maximum velocity to the average velocity is nearly constant at 1.7.

5. Approximately 39% of the total *time* for a motion is required for the acceleration of the hand irrespective of the length or type of motion.

6. Approximately 18% of the total *time* for a motion is required for motion at constant velocity. (The time for motion at constant velocity is independent of the kind of stops used but varies from 19% to 16% when the length of motion is increased from five inches to fifteen inches.)

7. Approximately 40% of the total *time* for a motion is required for retardation (or deceleration) for all distances when visual stops are used. When mechanical stops are used the time to decelerate increases from 20% to 30% when the distance is increased from five inches to fifteen inches.

8. The percentage of the total *time* required for changing direction of the hand decreases from 24% to 15% for mechanical stops and from 8% to 5% for visual stops when the length of motion is increased from five inches to fifteen inches.

9. Motions using visual stops required approximately 17% more time than did motions using mechanical stops.

TABLE VIII

RESULT SHEET

These data are the average results of the twenty-eight operators studied
The upper values for curves of the same type are for movement away from the operator;
the lower for movement toward the operator

	Time in thousandths of a sec.					Distance in inches				Velocity inches/sec		Ratio	T_a, T_p, T_d, T_o in per cent of total time				S_a, S_p, S_d in per cent of total distance		
Curve Type	T_a	T_p	T_d	T_o	T	S_a	S_p	S_d	S	V_p	V	V_p/V	T_a/T	T_p/T	T_d/T	T_o/T	S_a/S	S_p/S	S_d/S
1A	157	75	78	95	405	2.05	1.63	1.32	5.00	23.7	13.2	1.80	38.8	18.5	19.3	23.4	41.0	32.6	26.4
1A	155	77	82	96	410	1.94	1.70	1.36	5.00	22.6	13.2	1.73	38.8	17.8	20.0	23.4	38.8	34.0	27.2
1B	178	85	185	34	482	1.78	1.47	1.77	5.02	19.5	11.6	1.68	37.0	17.6	38.4	7.0	35.5	29.3	35.2
1B	184	88	176	37	485	1.71	1.51	1.77	4.99	19.2	11.4	1.69	38.0	18.1	36.3	7.6	34.3	30.2	35.5
2A	172	83	125	80	460	3.76	2.97	3.27	10.00	37.3	22.3	1.67	37.4	18.0	27.2	17.4	37.6	29.7	32.7
2A	181	83	114	76	454	3.96	3.07	2.97	10.00	38.1	20.5	1.86	40.0	18.2	25.1	16.7	39.6	30.7	29.7
2B	201	89	229	26	545	3.53	2.85	3.70	10.08	32.7	20.0	1.64	36.9	16.3	42.0	4.8	35.0	28.2	36.8
2B	212	91	198	32	533	3.73	2.83	3.50	10.06	32.7	19.9	1.64	39.7	17.1	37.2	6.0	37.0	28.1	34.9
3A	185	84	167	74	510	5.34	4.08	5.35	14.77	49.6	29.6	1.67	36.3	16.4	32.8	14.5	36.2	27.6	36.2
3A	205	89	137	75	506	5.70	4.20	4.87	14.77	49.5	30.0	1.65	40.5	17.6	27.1	14.8	38.6	28.4	33.0
3B	223	91	250	26	590	5.15	3.93	5.90	14.98	43.8	24.5	1.79	37.8	15.4	42.4	4.4	34.4	26.2	39.4
3B	246	96	214	30	586	5.80	4.20	4.87	14.87	44.8	26.5	1.69	42.0	16.3	36.6	5.1	39.2	28.0	32.8

1A Movement on slide Mechanical stops 5″
2A Movement on slide Mechanical stops 10″
3A Movement on slide Mechanical stops 15″
1B Movement on slide Visual stops 5″
2B Movement on slide Visual stops 10″
3B Movement on slide Visual stops 15″

Subscript a denotes period of acceleration
Subscript p denotes period of constant velocity
Subscript d denotes period of deceleration
Subscript o denotes period of changing direction
No subscript denotes total element for one-half cycle.

10. Approximately 38% of the total *distance* or length of the hand motion is required for acceleration irrespective of the length or type of motion.

11. The percentage of the total *distance* required for motion at constant velocity decreases from approximately 33% to 28% for mechanical stops and from 30% to 27% for visual stops when the length of motion is increased from five to fifteen inches.

12. Approximately 36% of the total *distance* or length of hand motion is required for retardation (or deceleration) for visual stops; and varies from 27% to 35% for mechanical stops as the motion is increased from five to fifteen inches.

X. APPENDIX

TABLE IX

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C17; Operator No. A2; Date, July 31; Distance, 8 inches;
Camera Speed, 1000 frames per minute; Time in minutes

		Symbol	Right Hand Description	Cycle Number 1	2	3	4	5	6	7	8	9	Av.
I	A	T.E.	Reaches for material	.004	.004	.003	.004	.004	.004	.003	.004	.003	.0037
II	B	St.	Selects one piece	.004	.003	.007	.003	.003	.003	.009	.003	.003	.0042
	C	G.	Grasps one piece										
III	D	T.L.	Carries piece to fixture	.004	.004	.004	.004	.004	.004	.004	.004	.004	.0040
IV	E	P.	Inserts piece in fixture	.008	.011	.008	.007	.014*	.007	.011	.006	.006	.0080
	F	R.L.	Releases piece										
V	G	T.E.	Reaches for forming lever	.007	.007	.007	.008	.007	.007	.007	.007	.007	.0071
	H	G.	Grasps forming lever knob										
	J	U.	Forms 1st end of link										
VI	K	T.L.	Returns forming lever	.003	.003	.003	.003	.003	.004	.003	.003	.003	.0031
	L	R.L.	Releases forming lever										
VII	M	T.E.	Moves hand toward fixture	.027	.037	.016	.031	.030	.016	.024	.032	.027	.0266
	N	U.D.	Waits for left hand										
	P	T.E.	Moves hand toward fixture										
	Q	P.	Assists L. Hand in turning pc. end for end in fixture										
VIII	R	T.E.	Reaches for forming lever	.007	.007	.007	.007	.007	.007	.007	.007	.007	.0070
	S	G.	Grasps forming lever knob										
	T	U.	Forms 2nd end of link										
IX	U	T.L.	Returns forming lever	.003	.003	.004	.003	.003	.004	.003	.003	.003	.0032
	V	R.L.	Releases forming lever										
			Total time in minutes	.067	.079	.059	.070	.075	.056	.071	.069	.063	.0677

*fumble .008

TABLE X

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C18; Operator No. A2; Date, July 31; Distance, 16 inches;
Camera Speed, 1000 Frames per minute; Time in minutes

		Symbol	Right Hand Description	Cycle Number 1	2	3	4	5	6	7	8	9	10	11	Av.
I	A	T.E.	Reaches for material	.004	.004	.004	.003	.003	.004	.003	.003	.004	.003	.004	.0035
II	B	St.	Selects one piece	.002	.005	.006	.004	.004	.005	.002	.014	.002	.003	.010	.0052
	C	G.	Grasps one piece												
III	D	T.L.	Carries piece to fixture	.005	.006	.006	.005	.006	.006	.006	.006	.006	.006	.005	.0057
IV	E	P.	Inserts piece in fixture	.006	.004*	.005	.005	.005	.004	.007	.011	.006	.010	.019	.0075
	F	R.L.	Releases piece												
V	G	T.E.	Reaches for forming lever	.007	.007	.006	.007	.007	.007	.008	.007	.007	.007	.007	.0070
	H	G.	Grasps forming lever knob												
	J	U.	Forms 1st end of link												
VI	K	T.L.	Returns forming lever	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0030
	L	R.L.	Releases forming lever												
VII	M	T.E.	Moves hand toward fixture	.017	.020	.042	.023	.029	.015	.018	.017	.016	.015	.023	.0213
	N	U.D.	Waits for left hand												
	P	T.E.	Moves hand toward fixture												
	Q	P.	Assists L. Hand in turning pc. end for end in fixture												
VIII	R	T.E.	Reaches for forming lever	.006	.006	.907	.007	.007	.007	.007	.007	.007	.007	.007	.0068
	S	G.	Grasps forming lever knob												
	T	U.	Forms 2nd end of link												
IX	U	T.L.	Returns forming lever	.003	.003	.004	.003	.002	.003	.003	.003	.003	.003	.003	.0030
	V	R.L.	Releases forming lever												
			Total time in minutes	.053	.058	.083	.060	.066	.054	.057	.071	.054	.057	.081	.0630

*fumble .013

TABLE XI

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C19; Operator No. A2; Date, July 31; Distance, 24 inches; Camera Speed, 1000 frames per minute; Time in minutes

		Symbol	Right Hand Description	Cycle Number 1	2	3	4	5	6	7	8	9	10	11	Av.
I	A	T.E.	Reaches for material	.005	.005	.005	.004	.005	.005	.005	.005	.005	.005	.005	.0049
II	B C	St. G.	Selects one piece Grasps one piece	.003	.003	.004	.006	.004	.002	.004	.009	.003	.003	.003	.0038
III	D	T.L.	Carries piece to fixture	.006	.007	.006	.006	.005	.006	.006	.006	.006	.006	.006	.0059
IV	E F	P. R.L.	Inserts piece in fixture Releases piece	.006	.005	.008	.005	.006*	.006	.006	.009	.006	.009	.006	.0067
V	G H J	T.E. G. U.	Reaches for forming lever Grasps forming lever knob Forms 1st end of link	.007	.008	.007	.008	.009	.008	.007	.007	.007	.007	.007	.0075
VI	K L	T.L. R.L.	Returns forming lever Releases forming lever	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0031
VII	M N P Q	T.E. U.D. T.E. P.	Moves hand toward fixture Waits for left hand Moves hand toward fixture Assists L. Hand in turning pc. end for end in fixture	.016	.016	.017	.027	.015	.017	.016	.015	.022	.021	.015	.0175
VIII	R S T	T.E. G. U.	Reaches for forming lever Grasps forming lever knob Forms 2nd end of link	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.0071
IX	U V	T.L. R.L.	Returns forming lever Releases forming lever	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0031
			Total time in minutes	.056	.057	.060	.069	.057	.057	.057	.064	.062	.064	.055	.0596

* false motion .006

NOTE: Due to lack of space data for cycles 12 to 16 inclusive have been omitted from this table.

TABLE XII

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C20; Operator No. A1; Date, July 31; Distance, 8 inches; Camera Speed, 1000 frames per minute; Time in minutes

	Symbol		Right Hand Description	Cycle Number 1	2	3	4	5	6	Av.
I	A	T.E.	Reaches for material	.004	.004	.004	.004	.003	.003	.0037
II	B	St.	Selects one piece	.004	.003	.003	.003	.002	.003	.0030
	C	G.	Grasps one piece							
III	D	T.L.	Carries piece to fixture	.005	.005	.005	.005	.005	.005	.0050
IV	E	P.	Inserts piece in fixture	.005	.006	.006	.005	.006	.012	.0049
	F	R.L.	Releases piece							
V	G	T.E.	Reaches for forming lever	.010	.010	.010	.010	.010	.010	.0100
	H	G.	Grasps forming lever knob							
	J	U.	Forms 1st end of link							
VI	K	T.L.	Returns forming lever	.006	.006	.006	.006	.007	.006	.0062
	L	R.L.	Releases forming lever							
VII	M	T.E.	Moves hand toward fixture	.036	.024	.017	.017	.014	.016	.0206
	N	U.D.	Waits for left hand							
	P	T.E.	Moves hand toward fixture							
	Q	P.	Assists L. Hand in turning pc. end for end in fixture							
VIII	R	T.E.	Reaches for forming lever	.010	.011	.010	.010	.010	.010	.0102
	S	G.	Grasps forming lever knob							
	T	U.	Forms 2nd end of link							
IX	U	T.L.	Returns forming lever	.006	.006	.006	.006	.006	.005	.0058
	V	T.E.	Releases forming lever							
			Total time in minutes	.086	.075	.067	.066	.063	.070	.0712

TABLE XIII

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C21; Operator No. A1; Date, July 31; Distance, 16 inches; Camera Speed, 1000 frames per minute; Time in minutes

		Symbol	Right Hand Description	Cycle Number 1	2	3	4	5	6	Av.
I	A	T.E.	Reaches for material	.006	.005	.005	.005	.006	.005	.0053
II	B	St.	Selects one piece	.008	.003	.007	.003	.004	.002	.0045
	C	G.	Grasps one piece							
III	D	T.L.	Carries piece to fixture	.010	.007	.006	.006	.006	.007	.0070
IV	E	P.	Inserts piece in fixture	.016	.008	.017	.024	.007	.005	.0128
	F	R.L.	Releases piece							
V	G	T.E.	Reaches for forming lever	.010	.011	.010	.011	.010	.010	.0103
	H	G.	Grasps forming lever knob							
	J	U.	Forms 1st end of link							
VI	K	T.L.	Returns forming lever	.008	.005	.006	.005	.005	.006	.0058
	L	R.L.	Releases forming lever							
VII	M	T.E.	Moves hand toward fixture	.018	.017	.028	.016	.016	.019	.0190
	N	U.D.	Waits for left hand							
	P	T.E.	Moves hand toward fixture							
	Q	P.	Assists L. Hand in turning pc. end for end in fixture							
VIII	R	T.E.	Reaches for forming lever	.010	.011	.011	.010	.010	.011	.0105
	S	G.	Grasps forming lever knob							
	T	U.	Forms 2nd end of link							
IX	U	T.L.	Returns forming lever	.006	.005	.005	.006	.006	.005	.0055
	V	T.E.	Releases forming lever							
			Total time in minutes	.092	.072	.095	.086	.070	.070	.0808

TABLE XIV

OPERATION: FORM LINK FOR TYPEWRITER

Study No. C22; Operator No. A1; Date, July 31; Distance, 24 inches;
Camera Speed, 1000 frames per minute; Time in minutes

	Symbol		Right Hand Description	Cycle Number 1	2	3	4	5	6	7	8	9	10	11	Av.
I	A	T.E.	Reaches for material	.008	.007	.007	.007	.007	.006	.006	.006	.006	.007	.006	.0066
II	B	St.	Selects one piece	.008	.003	.002	.009	.005	.006	.007	.003	.002	.003	.005	.0048
	C	G.	Grasps one piece												
III	D	T.L.	Carries piece to fixture	.007	.007	.008	.009	.012	.008	.008	.007	.008	.006	.008	.0080
IV	E	P.	Inserts piece in fixture	.007	.017	.005	.036	.010	.012	.011	.007	.007	.013	.013	.0125
	F	R.L.	Releases piece												
V	G	T.E.	Reaches for forming lever	.010	.010	.010	.010	.010	.009	.010	.010	.009	.010*	.009	.0097
	H	G.	Grasps forming lever knob												
	J	U.	Forms 1st end of link												
VI	K	T.L.	Returns forming lever	.006	.005	.005	.006	.006	.006	.006	.006	.006	.006	.007	.0059
	L	R.L.	Releases forming lever												
VII	M	T.E.	Moves hand toward fixture	.017	.022	.018	.022	.019	.018	.018	.018	.018	.018	.017	.0186
	N	U.D.	Waits for left hand												
	P	T.E.	Moves hand toward fixture												
	Q	P.	Assists L. Hand in turning pc. end for end in fixture												
VIII	R	T.E.	Reaches for forming lever	.010	.009	.010	.010	.009	.010	.010	.010	.010	.010	.010	.0098
	S	G.	Grasps forming lever knob												
	T	U.	Forms 2nd end of link												
IX	U	T.L.	Returns forming lever	.005	.006	.006	.005	.006	.006	.006	.006	.006	.006	.006	.0058
	V	R.L.	Releases forming lever												
			Total time in minutes	.078	.086	.071	.114	.084	.081	.082	.073	.082	.079	.081	.0828

*false motion .011

TABLE XV

OPERATION: FORM LINK FOR TYPEWRITER

Study No. X51; Operator No. A2; Date, July 26; Location of Material, Scattered on Mat; Camera Speed, 2000 frames per minute; Time in minutes

	Symbol		Right Hand Description	Cycle Number 1	2	3	4	5	6	Av.
I	A	T.E.	Reaches for material	.0060	.0065	.0065	.0060	.0055	.0060	.00608
II	B	St.	Selects one piece	.0050	.0050	.0050	.0040	.0110	.0035	.00558
	C	G.	Grasps one piece							
III	D	T.L.	Carries piece to fixture	.0050	.0035	.0050	.0050	.0080	.0050	.00525
IV	E	P.	Inserts piece in fixture	.0095	.0100	.0130	.0110	.0115	.0090	.01066
	F	R.L.	Releases piece							
V	G	T.E.	Reaches for forming lever	.0020	.0020	.0020	.0020	.0020	.0015	.00192
	H	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	J	U.	Forms 1st end of link	.0060	.0060	.0060	.0060	.0060	.0065	.00608
VI	K	T.L.	Returns forming lever	.0020	.0020	.0020	.0020	.0020	.0020	.00200
	L	R.L.	Releases forming lever							
VII	M	T.E.	Moves hand toward fixture	.0040	.0050	.0045	.0040	.0045	.0050	.00450
	N	U.D.	Waits for left hand	.0075	.0060	.0055	.0060	.0060	.0055	.00608
	P	T.E.	Moves hand to fixture	.0215	.0130	.0150	.0115	.0215	.0110	.01558
	Q	P.	Assists L. Hand in turning pc. end for end in fixture							
VIII	R	T.E.	Reaches for forming lever	.0015	.0020	.0020	.0015	.0015	.0020	.00175
	S	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	T	U.	Forms 2nd end of link	.0060	.0060	.0060	.0065	.0065	.0065	.00625
IX	U	T.L.	Returns forming lever	.0020	.0025	.0025	.0020	.0020	.0020	.00217
	V	R.L.	Releases forming lever							
			Total time in minutes	.0790	.0705	.0760	.0685	.0890	.0665	.07492

TABLE XVI

OPERATION: FORM LINK FOR TYPEWRITER

Study No. X52; Operator No. A2; Date, July 26; Camera Speed, 2000 frames per minute; Location of material, vertical in holes; Time in minutes

	Symbol		Right Hand Description	Cycle Number 1	2	3	4	5	6	7	8	9	Av.
I	A	T.E.	Reaches for material	.0055	.0055	.0060	.0050	.0050	.0055	.0065	.0060	.0055	.00554
II	B C	St. G.	Selects one piece Grasps one piece	.0020	.0020	.0030	.0025	.0025	.0020	.0045	.0055	.0025	.00279
III	D	T.L.	Carries piece to fixture	.0060	.0060	.0060	.0060	.0060	.0055	.0090	.0050	.0055	.00608
IV	E F	P. R.L.	Inserts piece in fixture Releases piece	.0080	.0070	.0075	.0065	.0175	.0070	.0070	.0070	.0130	.00866
V	G	T.E.	Reaches for forming lever	.0015	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.00196
	H	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	J	U.	Forms 1st end of link	.0065	.0060	.0060	.0060	.0060	.0055	.0055	.0060	.0080	.00613
VI	K L	T.L. R.L.	Returns forming lever Releases forming lever	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.00250
VII	M	T.E.	Moves hand toward fixture	.0040	.0045	.0045	.0045	.0050	.0050	.0050	.0045	.0045	.00463
	N	U.D.	Waits for left hand	.0050	.0050	.0050	.0050	.0035	.0050	.0050	.0075	.0055	.00604
	P Q	T.E. P.	Moves hand to fixture Assists L. Hand in turning pc. end for end in fixture	.0230	.0105	.0200	.0125	.0115	.0105	.0095	.0180	.0130	.01396
VIII	R	T.E.	Reaches for forming lever	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.00200
	S	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	T	U.	Forms 2nd end of link	.0060	.0060	.0060	.0060	.0055	.0065	.0055	.0060	.0060	.00596
IX	U V	T.L. R.L.	Returns forming lever Releases forming lever	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.0025	.00250
			Total time in minutes	.0755	.0625	.0740	.0640	.0725	.0625	.0675	.0755	.0735	.06975

NOTE: Due to lack of space data for c cles 10, 11 and 12 have been omitted from this table.

TABLE XVII

OPERATION: FORM LINK FOR TYPEWRITER

Study No. X53; Operator No. A2; Date, July 26; Camera Speed, 2000 frames per minute; Location of Material, Horizontal in slots cut in wood block; Time in minutes

	Symbol		Right Hand Description	Cycle Number 1	2	3	4	5	6	Av.
I	A	T.E.	Reaches for material	.0060	.0060	.0055	.0065	.0060	.0060	.00600
II	B	St.	Selects one piece							
	C	G.	Grasps one piece	.0020	.0020	.0030	.0020	.0020	.0025	.00225
III	D	T.L.	Carries piece to fixture	.0055	.0055	.0050	.0055	.0055	.0055	.00542
IV	E	P.	Inserts piece in fixture							
	F	R.L.	Releases piece	.0065	.0070	.0120	.0075	.0075	.0075	.00800
V	G	T.E.	Reaches for forming lever	.0020	.0020	.0020	.0020	.0015	.0020	.00192
	H	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	J	U.	Forms 1st end of link	.0060	.0055	.0060	.0055	.0060	.0060	.00583
VI	K	T.L.	Returns forming lever							
	L	R.L.	Releases forming lever	.0025	.0025	.0025	.0025	.0030	.0025	.00258
VII	M	T.E.	Moves hand toward fixture	.0045	.0045	.0045	.0045	.0040	.0050	.00450
	N	U.D.	Waits for left hand	.0055	.0050	.0050	.0055	.0065	.0060	.00558
	P	T.E.	Moves hand to fixture							
	Q	P.	Assists L. Hand in turning pc. end for end in fixture	.0105	.0105	.0110	.0120	.0110	.0110	.01100
VIII	R	T.E.	Reaches for forming lever	.0020	.0020	.0020	.0020	.0020	.0020	.00200
	S	G.	Grasps forming lever knob	.0005	.0005	.0005	.0005	.0005	.0005	.00050
	T	U.	Forms 2nd end of link	.0055	.0055	.0055	.0055	.0055	.0060	.00558
IX	U	T.L.	Returns forming lever							
	V	R.L.	Releases forming lever	.0030	.0025	.0025	.0025	.0030	.0025	.00267
			Total time in minutes	.0625	.0615	.0675	.0645	.0645	.0655	.06433

NOTE: Due to lack of space data for cycle seven have been omitted from this table.